GENERAL LIBRARY
UNIV. OF MICH.
DEC 14 1946

Journal
of
The Franklin Institute

NOVEMBER, 1946

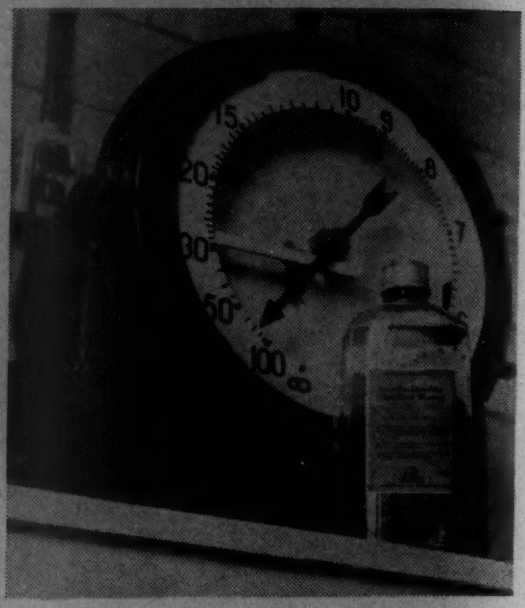
1826 1946

Published Monthly by

THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

LANCASTER, PA. PHILADELPHIA, PA.

GUARDIAN for a Water Still



An overall check of the purity of water from any automatic still is provided by a Micromax Recorder of the type shown here.

This instrument can warn the chemist or biologist against such difficulties as using water before entrained air has been swept out of the still. It also warns if improper or careless operation causes foaming or priming, and thus carries undistilled water to the effluent. Regardless of cause, if the effluent isn't of the desired conductivity, the Micromax indicates the fact, and can of course operate an alarm light or bell if required.

One of the equipment's greatest advantages, in a large laboratory, is that the automatically-drawn record chart gives written proof of water purity.

Catalog EN-95 describes the equipment and will be sent on request, but if you have a definite application in mind, an L&N engineer will be glad to supply individualized information.

Upjohn Co., Kalamazoo, Mich., use this Micromax Recorder to show the constant purity of the sterile, double-distilled, pyrogen-free water which is one of their products. Shown below is the equipment's metal-boxed conductivity-cell assembly.

LEEDS & NORTHRUP COMPANY, 4992 STENTON AVE., PHILA., PA.

LEEDS & NORTHRUP

MEASURING INSTRUMENTS · TELEMETERS · AUTOMATIC CONTROLS · HEAT-TREATING FURNACES

Jrl. Ad N-95(3c)

Journal
of
The Franklin Institute

EDITOR, HENRY BUTLER ALLEN, MET.E., D.Sc.
ASSISTANT EDITOR, JOHN FRAZER, PH.D.

Associate Editors:

WILDER D. BANCROFT, PH.D. — PAUL D. FOOTE, PH.D. — HENRY C. SHERMAN, SC.D.
C. B. BAZZONI, PH.D. — W. J. HUMPHREYS, PH.D. — W. F. G. SWANN, D.SC.
ARTHUR L. DAY, SC.D. — C. E. K. MEES, D.SC. — HUGH S. TAYLOR, D.SC.
R. EKSERGIAN, PH.D. — WILLIAM B. MELDRUM, PH.D. — A. F. ZAHM, PH.D.
A. S. EVE, F.R.S. — JOHN ZELENY, PH.D.

Committee on Publications:

G. H. CLAMER, CHAIRMAN — LIONEL F. LEVY — HIRAM S. LUKENS
RICHARD HOWSON — MALCOLM LLOYD, JR. — RICHARD H. OPPERMANN
C. L. JORDAN — WINTHROP R. WRIGHT

Vol. 242 — **NOVEMBER, 1946** — **No. 5**

CONTENTS

Vermilye Medal Dinner ..... C. S. REDDING 343

Railroads in the War ..... M. W. CLEMENT 345

The Interconnection of Dead-Reckoning and Radar Data for Precision Navigation and Prediction ..... BRITTON CHANCE 355

GPI—An Automatic Navigational Computer .... W. J. TULL AND N. W. MACLEAN 373

The Prospects of Conservancy Works in China ..... BAZIN SHEN 399

The Franklin Institute Notes 421

Notes from the Biochemical Research Foundation 424

Ribonucleinase and Non-Specific Phosphodiesterase in Rat and Rabbit Blood and Tissues ..... CHARLES A. ZITTLE AND ELIZABETH H. READING

Book Reviews 429

Publications Received 430

Current Topics 431

Published by
THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA
Prince and Lemon Streets, Lancaster, Penna., and
Benjamin Franklin Parkway at Twentieth St., Philadelphia 3, Penna.

SIX DOLLARS PER YEAR (Foreign Postage Additional) SINGLE NUMBERS, SIXTY CENTS
Indexes to the semi-annual volumes of the JOURNAL are published with the June and December numbers

PHILCO

Famous for Quality

the World Over

RADIOS • PHONOGRAPHS • FM • TELEVISION

REFRIGERATORS • FREEZERS • AIR CONDITIONERS

Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 242 NOVEMBER, 1946 No. 5

VERMILYE MEDAL DINNER.*

THE FRANKLIN INSTITUTE, Friday, October 4, 1946

It is with much pleasure that, as President of The Franklin Institute, I welcome you tonight. We are here to do honor to a great man and a great Philadelphian. This honor is being bestowed by a great institution in which we all take a pardonable pride.

As I stand here I wonder what those men who, in 1824, founded The Franklin Institute would think if they could return to us today and view their child grown to maturity. Were that possible we would take them on a tour of our *great museum.* We would tell them of the thousands upon thousands of men, women, and, particularly, children who, year after year, profit by the educational exhibits here available.

We would take them to a *planetarium* demonstration and amaze them with the device which makes it possible to so clearly demonstrate the wonders of the skies.

We would take them to our *library*, one of the finest and most complete scientific libraries in the country.

We would show them the files of the JOURNAL which for 121 years has disseminated scientific information throughout the world.

We would show them the complete records of our *Committee on Science and the Arts* which, through the years, has been seeking out men and women who have done notable scientific work, and recommending them for Franklin Institute awards which are known and prized throughout the world.

We would take them into our *lecture hall* and satisfy them that their original desire, that opportunity be given our citizens to see and hear at first-hand those who are doing notable scientific work, is still being carried on.

We would take them to *Swarthmore* and show them the Bartol Research Laboratories where pioneer work is being done in pure physics.

* Address delivered on the occasion of the award of the Vermilye Medal to M. W. Clement, October 4, 1946.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

Then, on to Newark, Delaware, to the *Biochemical Research Laboratories*. Although those laboratories are not an integral part of The Franklin Institute, they are administered by the Institute. They would be intrigued by the fine work which is being done there in developing ways and means for combating disease.

We would take them into this *great hall*, dedicated to the memory of our patron Benjamin Franklin, and they would gaze with admiration upon this beautiful statue.

Then we would tell them something of the fine research and development work which was so successfully done within these walls for the Armed Services during the late war and of the honors received by the Institute and its staff for that work.

Then we would tell them of our decision to continue our research and development work into peace times, both for the government and industry, not only because it affords an opportunity for further service but also because we expect it to provide the means for enlarging the other institute services.

They would be surprised that within these walls we now have 338 individuals at work, and that in the Bartol and Biochemical Laboratories we have an additional 87, making a total payroll of 425.

Then, finally, we would bring them to this dinner at which they would witness the presentation of one of our newer medals, the Vermilye Medal, and now I shall ask Mr. Philip C. Staples, a Past President of the Institute and a member of its Board of Managers, and Chairman of the Vermilye Medal Committee, to speak to them and to you.

Mr. Staples.

C. S. REDDING.

RAILROADS IN THE WAR.

An Address by Mr. M. W. Clement, President, Pennsylvania Railroad, on the Occasion of the Award to him of the Vermilye Medal of The Franklin Institute, October 4, 1946.

The story of the railroads in this war is a story of organization and preparedness, and the rail transportation efficiency of this war had its beginning in the last war!

After the breakdown of the national transportation system under government operation in World War No. 1 the railroads were returned to their owners, who assured the people of the United States that if permitted to operate at a proper return, management would rehabilitate the railroads not only to carry the volume of business offered but to improve the service by which that business was to be handled. That was the great job of the '20s!

The railroads spent billions upon billions—ten of them to rehabilitate the national transportation system. Yards, terminals and lines were improved; tens of thousands upon tens of thousands of cars, new and larger, were built; and thousands upon thousands of bigger engines. The Pennsylvania Railroad alone added over a thousand new modern engines to its fleet. All this took place in the '20s, and when the peak load of that period came the railroads handled it without delay. In addition to preparing themselves for what was to come, they added much to the recovery of the country after the first World War. The fulfillment of that promise to the people not only enabled the railroads to ride out the great depression but enabled them to lay the foundation for the service they were able to perform in this war.

Concurrently with this great program of the railroads to eliminate the obsolescence that had crept into their property through the changing conditions brought about by the first war, there was an insistent demand among many people, resulting from the dissatisfaction with government operation in the first war, that the railroads of the country should be consolidated, and the Congress instructed the Interstate Commerce Commission to make up a plan for consolidating the railroads of the United States into a limited number of systems; and this consolidation was way out in front in the thinking of people of the country as we went into the depression in the early '30s.

But labor was very much opposed to consolidation because the results of it would be still fewer jobs in an industry that had already greatly reduced its employment; and as the depression made itself more and more felt the possibilities of financing any consolidations failed and

coordination became the thinking of the day supplanting consolidation in the minds of the people.

The railroads of the United States competitively serve within each of the different sections of the country but complement each other when it comes to serving the other sections. Similarly, they also interchange freely with the competitive railroads of Canada and the National Railways of Mexico. No one railroad serves the east, the west, and the south. Many roads serve the various sections of the country. It is only as they complement each other and are coordinated that they can serve the country as a whole; and, when it comes to war, the railroads must be coordinated. It was only through the Presidents of the railroads, getting together in their Association, that they were able to perform the railroad service they did in the war effort; and probably one of the greatest examples of foresight, so far as this war was concerned, was the fact that the railroads had established the Association of American Railroads and that when war came it was a going concern.

The government had its coordinator, and the railroads had theirs; and in this great country of ours where distances were lessening and communication through travel by the people spread to all points of the country—the development of the great resorts of the south and west, and the transportation of food from the many states to the larger cities—there developed the necessity that the American railroads, none of which served the entire country but each of which was complementary to the other, should have some way to coordinate their efforts, and it was then the Association of American Railroads was born.

It was a consolidation of many associations; it was a place where the problems of an industry that serves the whole country could be discussed by the component parts that make up the national rail transportation system. It was located in Washington where it was available for contact between the government and the railroads. Its great problem, of course, was the handling of the rules for interchange of equipment between one railroad and another, and preserving such standards of design that the cars of any railroad could move over all roads; to study improved design and to bring forth improved design. It was also at the Commission's beck and call, and it was the means of communication between the Commission, the Army, the Navy, and the other branches of the government with the railroads.

It is safe to say that no voluntary organization or association, without any authority of control whatever, has ever served a people any better than this organization was able to serve the people of the United States during this war; and it was through this organization that the first contacts came between the Army and Navy and the railroads prior to the war.

In the middle '30s when the signs of war in Europe were on the horizon, the Chiefs of Staff of the Army and Navy were doing what they

could to prepare this country for war, and one of the things that turned out to be most important to this country was their study of transportation. In the course of this study they learned of the pitfalls of transportation in World War No. 1 and how they could be avoided if again we went to war.

This is no place to discuss the problems of World War No. 1, but suffice it to say that there was absolutely no coordination between the trans-shipping by ocean and the shipping by rail, and that hundreds of thousands of carloads of freight were brought to the Atlantic Seaboard where there were no boats for handling, and where these loaded cars occupied the space that should have been used for handling the commerce of the country; so that it finally got to the point that everything was embargoed except government traffic and foodstuffs and the materials of commerce could only be had as permitted. Cars were backed up 200 miles from the coast; hundreds of thousands of tons of material for Russia were at tidewater and there was no Russia; miles and miles of main line were stored with cars loaded with materials for plants that did not exist. All these things were pointed out to the Army and Navy, and they were told that if the railroads were to function in this war the equipment of the railroads must not be used for storage warehouses, but that they should have great storage areas of their own, apart from railroad facilities, located at points where the goods could easily be brought to two or three or more terminals for trans-shipping as the boats were available, and that was done.

As we moved nearer to war in the late part of '38, the President of the United States asked the railroads to advise him of a plan which in private operation would assure that the railroads could handle the enlarged traffic which would be part of a national emergency such as war. He was advised that as long as the United States did not participate in the war the railroads could meet their responsibilities without any additional assistance, but that with the participation of the United States in the war there should be provided an officer in the Executive Department of the government in whom would be vested the authority to approve such measures of relief necessary to meet unusual and additional demands of a government at war. It was thought at the time that this man should be of Cabinet rank and should be on equal footing with the other Cabinet officers. From this recommendation, when war eventually broke out, came the executive order creating the Office of Defense Transportation; which while never given Cabinet rank, had as its Directors men who were members of the Interstate Commerce Commission. On account of their position they were able to exercise the authority necessary to contact and cooperate, or coordinate with the efforts of the other parts of the government, and in reporting directly to the President they brought this office to the stature of a war agency, giving it authority over all transportation and requiring all other de-

partments and agencies of the government to liaison with that office when such matters were of mutual interest.

It was further recommended to the government that as the costs of operation built up, the cost to the public should reflect those higher costs so as to ease the change in the rate structure at a time when it could well be absorbed; a recommendation carried out as we got into the war but later nullified.

When the European war broke out in September, 1939, the Association called all the railroad Presidents together in Washington where the pending situation was freely discussed. As the war came to England, the railroads of the United States prepared themselves for the war that it was felt surely sooner or later would involve this country, having in mind that Canada already had followed England in her declaration. It was more than fortunate for the country that the men who were directly responsible for the railroads at the outbreak of the war in Europe had served on the railroads in the previous war and were familiar, by experience, with wartime transportation. They were well aware of the necessity for cars and locomotives, both passenger and freight, and they immediately proceeded to strengthen their plant, not only in the repairing of all equipment in unserviceable condition that had been standing idle all the years of the depression, but also in providing for new and modern rolling stock, strengthening their plant in improvements at ports, in critical yards, on main tracks, and providing them with signalling for more quickly and safely moving trains.

The Pennsylvania Railroad alone had tens upon tens of thousands of freight cars standing idle, most of which were in need of repair if they were to be used again, and almost half of them were ready for scrap if not needed to meet an emergency. We had hundreds upon hundreds of steam locomotives, too small for the future, ready either for sale or teardown. We had hundreds of passenger cars—steel, to be sure; but not modernized—and there was question whether they ever would be needed for normal traffic. Many of our harbor facilities had not been intensively used for years and, due to the depression, needed a great deal of rehabilitation.

What was true on the Pennsylvania Railroad was true on every railroad in this country as well as in Canada and Mexico; but these roads set about to prepare themselves for the emergency that was to come by repairing rolling equipment and making it available for war service and repairing generally their fixed facilities.

As railroad management has always had its Association of chief executives, so has railroad labor long had its Association of executives.

Railroad labor executives understood with the executives of the railroads what was going to take place, and labor appointed a contact committee of union officers to meet with a contact committee of railroad officers in order that we might get through this war without any

interruption of transportation service and with the avoidance of conflict between labor and management. Railroad management and railroad labor both had seen the disturbances of the previous war. They knew the necessity for something to eliminate that conflict. The Railway Labor Act, in its original form, was conceived by those who had been through all the disturbances of the previous war and had planned to avoid such troubles in the future.

With the determination of men and management that there would not be interruption of service, and with the machinery that previously had been set up, we got through the war. The only time the Railway Labor Act did not function, as it had been intended to function, was when there was interference by the government at the highest level, after Presidential Emergency Boards had recommended wage increases.

The Railway Labor Act, at its inception, provided that when there were threats of interruption to transportation, the President should appoint a fact-finding board and both sides stand aside until determination could be made. In its functioning the only possible way labor could get to a fact-finding board was through threatening to strike, the taking of a strike vote with all the ensuing publicity that accompanies such a procedure, and as the Act now functions practically all disturbances eventually get to fact-finding, and it should be possible to get there without threatening strike. It was this clause under the Act that caused the threatened strike during the war and led up to the necessity of going through the gesture of government seizure of the railroads when everything continued to function on the railroads the same before, during, and after it was all over.

We met the problem of employment; we met the problem of seniority and employment after the cessation of hostilities. They were all clearly defined and understood by both men and management before we got into the war. But one of the things that was difficult for many of us to understand was that under the Selective Service Regulations the transportation business was given only a second-class priority rating for deferment of its men, while ocean transportation and civilians in research and development enjoyed exemption. This caused an enormous employment problem for the railroads and other forms of transportation.

When war broke out in Europe, it was necessary for us to build up our forces and this we did out of the young men of America who, by reason of the depression, had not had employment. We built up our forces almost entirely with men in their twenties, but then the draft came along, taking men from 21 to 45, and we were forced to move down to employing men in their 'teens. Again the draft moved down as we had, and the Pennsylvania Railroad, which had been down to about one hundred thousand men when war broke out, eventually found itself with some 56,000 of its men in the Armed Services—a number equal to about

one-half our total employment in the depression years, working short time; and over one-third of our total employment in normal years.

That gave us a new employment problem. Our business has always been recognized as a man's business. There were only about 2,300 women on the Pennsylvania Railroad when the war broke out, but at the height of the war we had ten times that many, hired to do a man's work while the men were off to war. These women went into the train service, into the shop forces, into the stations, into the clerical forces, and, be it said to their everlasting credit, they did a remarkable job.

As the shortage of manpower still further developed, it was necessary to go outside the country, and the Pennsylvania Railroad employed and transported some 14,000 Mexicans to the States to supplement our forces.

At the peak movement on the railroads, the employes worked long hours of overtime. Too much credit cannot be given to the army of men and women who carried the railroads through the critical war period without interruption of service.

But, through all the war—and giving due credit to all the endeavors of the railroads as well as all industry—the Armed Forces were supreme. It is not necessary to emphasize here the magnitude of the war job performed by the industries of this country. But the point I do want to emphasize is that never in the history of the world was there a more efficiently and better organized Army and Navy than the Army and Navy of the United States in the past war—coming up from almost nothing, as they did, to the millions who served well. It is to the undying credit of the Captains and Majors and Lieutenant Colonels of the Regular Army, and to their counterparts in the Regular Navy, who took over the positions of Major and Lieutenant Generals and Admirals and who built up the organizations to function as they did.

The Chief of Staff, the Chief of Services of Supply, the Chief of Transportation—Army Service Forces, all will long be more than names to the railroad men of the United States. They built up a great organization, and as far as rail transportation was concerned they synchronized the military requirements through the Association of American Railroads and, using the legal authority of the Office of Defense Transportation, to an accord that worked "hand in glove," calling for enormous volumes of transportation and in turn getting it. No one, speaking from the standpoint of rail transportation in the United States, can ever be too complimentary to the Army and Navy.

There was no time from Pearl Harbor to the end of the hostilities when any failure on the part of the Armed Forces to coordinate the great volume of their shipments with the transportation available, could not have resulted in a serious tie-up of the nation's transportation system. Never was so great a volume of traffic handled with so little congestion.

The railroads too had their own problem of supply. While we are primarily built of steel, we also are one of the largest consumers of wood and the non-ferrous metals such as copper, zinc, tin, lead. When the war broke out in Europe there still was little demand for the metals in this country, and we on the Pennsylvania stocked up to a year's supply and continued to buy, keeping pace with consumption, as long as the materials could be bought.

The Pennsylvania Railroad, and other railroads, switched from one material to another to meet their necessities. They rehabilitated railroad passenger equipment so long as they could get materials. First they were shut off on air-conditioning equipment; then on car seats; next on this, and then on that—so that not only the building but the rebuilding and rehabilitation of railroad passenger equipment became impossible.

The same was true of freight equipment. Entirely a road of steel equipment, the Pennsylvania Railroad re-designed its freight cars so that the bodies of the cars could be made practically of wood, to save plates of steel needed for ships and the military; and when conversely, wood became scarce and steel again was available, we turned back to the use of steel.

In 1939, we started to build additional electric locomotives and continued through 1942 as long as copper and motor parts were available; and we did the same with steam locomotives as well as with Diesel-electrics: we built every kind of power that was possible within the limits allowed by the restrictions of the War Production Board and the capacity of the electric power companies to supply the energy.

Finally, a point was reached where all our supplies and all of our repairs and improvements, so far as materials were concerned, were under the control of the War Production Board. At the same time, the draft had reduced our skilled working forces. This condition involved coordination between the railroads, the Office of Defense Transportation, the Army and Navy, the War Production Board, and all other government departments and offices. In 1943, scarce critical materials were supplied to transportation as well as other important war activities only by material allocation of the War Production Board. At times, the margins were close, but in the end the goal was met and rail transportation functioned so well that our military forces in their world-wide distribution were never handicapped by lack of service from the railroads.

Probably one of the most difficult problems that faced the railroads in the war was the problem of capacity.

The railroads were built to serve the Nation's commerce and, as commerce grew, the railroads grew. Where coal is mined, the branch lines run into coal fields and the coal is brought to assembly yards where the cars are classified and moved to destination. In serving the steel

industry, the railroads and the steel industry have large yards side by side for the receiving and dispatching of the raw and finished products of that industry.

There are yards to serve the cities, both passenger and freight. They serve the purpose for which they were created and they have a capacity for normal business; but war upsets that. War changes the flow of materials. Coal that normally moved from Norfolk by boat now moved all the way to New York by rail. Materials that seldom moved for export now moved in train-load lots, and materials that before had never or seldom moved at all were moving in train-load after train-load. These all had to go to the waterfronts, where thousands of cars had to be handled at points and under conditions where hundreds were usually handled. Up and down the seaboard, from Norfolk to New York, the Pennsylvania Railroad built or rebuilt terminals to over ten thousand additional car capacity.

Where passenger trains had moved by twenties, they now moved by fifties, and where they had moved by hundreds they now moved by the two hundreds; and the Pennsylvania's line between New York and Washington—before the war generally considered a two-track line between Wilmington and Washington for 120 to 125 trains a day as a normal load—got up to between 225 and 250 trains a day. As the load gradually increased, the railroad gradually enlarged its capacity by equipping some of its tracks with double-direction signalling so that each track might be used in either direction at any time; and from the Susquehanna River to Washington additional trackage was added nearly all the way.

The New York, Baltimore, and Philadelphia terminals were all very much enlarged. Export business through Philadelphia increased substantially, to where the Pennsylvania Railroad itself released as many as 300 cars in one day for export. The whole of South Philadelphia Yard was rebuilt in a short period of time, at an expenditure of some three million dollars, just to meet the war load.

With the movement of troops to and from the South and Southwest, it was necessary to increase both yards and main line, and hundreds of miles of tracks were added to the Pennsylvania Railroad. As the war grew, the whole railroad plant of the country grew, and on the Pennsylvania alone some hundreds of millions of dollars were spent for extraordinary repairs to and construction of road and equipment. The great problem of the railroads was to change themselves from carriers serving a limited section of the country to a coordinated unit serving the freight needs of the whole nation and the tremendous need for passenger transportation caused by the great pyramiding of the Armed Forces.

With the establishment of great training camps in the South, the passenger equipment of the Pennsylvania Railroad, as with all other railroads, went off its own lines and became the passenger equipment of

the country. In the latter part of '41, we were sending many of our cars south to handle the furloughed troops over the Christmas and New Year holidays; as a matter of fact there were over 200 of them in the South at the time of Pearl Harbor and, in addition to those 200 cars, we suddenly were called on for another 200 cars which were used along with other cars to take the Army to the Pacific Coast. Within a short period after the date of Pearl Harbor, some 600,000-odd troops were moved to various points in the United States, and all this occurred during the peak of the holiday travel of Christmas and New Year of 1941–42.

As the Army and Navy grew, their furloughs grew, and the passenger equipment of all the railroads of the United States became almost as though it were all of one great unit. While the cars were gradually worked back to the home station of the railroad whose name was emblazoned on their sides, nevertheless everywhere in the United States one could see cars of the Pennsylvania Railroad as well as cars of all the other roads—and that continued for four years.

With the growth of the military, there was a parallel industrial relocation which pyramided passenger transportation until there were three times as many people travelling on the Pennsylvania Railroad in '44 and '45 as there had been before the war. Many different kinds of cars were turned into passenger carrying equipment. All of the Pennsylvania's inspection cars were turned into passenger cars; some of the business cars and old Pullman cars were converted into coach passenger equipment; box cars were turned into passenger equipment. Some of the railroads initially converted box cars into troop sleepers, using baggage cars for troop kitchens. With the accelerated military troop movement requirements, the government built 2,400 troop sleepers adapted from the freight box car and supplemented these cars with 800 kitchen cars similarly constructed from box car design. During peak military travel, these only partly met the military requirements and put an overloaded and overcrowded condition upon the railroads' passenger carrying equipment.

The Pennsylvania Railroad, which normally served some 10 or 12 thousand meals a day in its dining cars, saw its meals jump to over 50 thousand a day—half of them served in diners and half from basket service built up to suit times and conditions.

All of these situations changed every month, every week, sometimes daily, and at times almost every hour, as the rush movement came for the troops; which meant that for four years neither night nor day for any minute did the office of the Chief of Passenger Transportation on the Pennsylvania Railroad ever close.

What was true of passenger transportation was also true of freight transportation. Lines with more than sufficient capacity to take care of their normal business had more business thrust upon them than they were physically designed to carry, necessitating the adding of more

tracks, more sidings, more yards, bigger locomotives, more signalling—everything to keep increasing the capacity as the demand grew month by month—all heading for a peak that would come and collapse almost in a moment and leaving useless or unneeded that which had taken months to create. That was the problem the railroads faced with their own money and their own facilities, without any hope of a continuing financial return on the huge investments which they had to make for the temporary expansion.

As one transportation service after another faltered or discontinued, the railroads were called on to carry on. As the coastwise carriers disappeared and the submarines drew off the oil barges, both the merchandise freight and the oil came to the railroads, until they were handling more than a million barrels of oil every day. The coal which formerly moved by water came to the rails. The traffic that formerly moved by truck, as it grew beyond the trucking capacity, came to the rails. The railroads absorbed everything that was offered until they were handling more than they ever had handled in their history.

When one compares this war with the previous war, with private ownership and operation versus government operation, it is found that in the government control and guaranty period of the previous war and the subsequent inflation period freight rates were increased almost a hundred per cent. and passenger fares were increased almost fifty per cent. In this war, when the railroads ended up they were moving freight at the same rates as were in effect before the war, and passenger fares in part had been increased only ten per cent., but much of the volume had moved at greatly reduced rates, particularly for troops on furlough who moved on about half the regular coach fare.

Railroads performed their war service without any increase in cost to the public, without any increase in cost to the country, and without any interruption in meeting the needs of the country. That at least is some measure of the war job done by the railroads of America.

THE INTERCONNECTION OF DEAD-RECKONING AND RADAR DATA FOR PRECISION NAVIGATION AND PREDICTION.

BY

BRITTON CHANCE, PhD.,†

Radiation Laboratory,* Massachusetts Institute of Technology.

1. 1. *Introduction.* Classical methods of pilotage depend upon the knowledge of a dead-reckoning position, the comparison of a chart of visible objects to what is actually seen, and the verification or correction of the dead-reckoning position by means of identification of visible objects with those presented on a chart. Pilotage of ships is relatively easy, since the ship often moves so slowly that adequate time is available for a detailed study of the visible objects for precise identification. For example, the shape of a water tank or the color of a lighthouse, etc., may be observed, and extensive descriptions of these objects are given in "Coast Pilot." For this reason, pilotage is both successful and safe for most ship operations. On the other hand, pilotage of aircraft is more difficult; the time for observation is much less, and the characteristics of most aircraft prohibit a slow and cautious approach to an unidentified object. In wartime visual pilotage is even more difficult, since a close approach to identifiable objects may be dangerous. Nevertheless, visual pilotage has been used extensively in military, commercial, and private aviation.

The best supplement to pilotage is good dead-reckoning data, since an approximately known position greatly reduces the probability of error in the identification of a distinctive object. In fact, dead reckoning is an essential part of all navigational procedures. It has, therefore, been recently instrumented by dead-reckoning indicators (DRI) or air-position indicators (API), the former being employed in ships and the latter in aircraft. These devices are singularly successful in ships, since the motion of the ship through the water is a fairly accurate representation of its motion with respect to fixed objects. On the other hand, the API is not so satisfactory for aircraft, since the effects of wind are neglected. Therefore, improvements of API have been made which include the effects of wind and are called ground-position indicators (GPI).

The dead-reckoning instruments may operate as indicated in the block diagram of Fig. 1. The north-south and east-west components

* This paper is based on work done for the Office of Scientific Research and Development under Contract OEMsr-262 with the Massachusetts Institute of Technology.

† Present address, Medicinshe Nobelinstitutet, Biokemisha Avdelningen, Hantveskaregatan 3, Stockholm, Sweden.

of the ship's speed are obtained from a polar-to-rectangular-coordinate resolver—in this case a sine-cosine potentiometer.[1] The polar data are obtained, of course, from the ship's compass and the ship's log. The rectangular components of the ship's motion are integrated in a negative-feedback integrator [2] to give the north-south and east-west distance traveled. These values may then be plotted on a chart with respect to a point of departure and give the dead-reckoning position.

The resolution from polar to rectangular coordinates and the integration of the velocity components are here indicated by means of a sine-cosine potentiometer and an electrical integrator. DRI's and API's may employ a scotch-yoke resolver and a ball-and-disc integrator in order that a mechanical output may be obtained which will directly

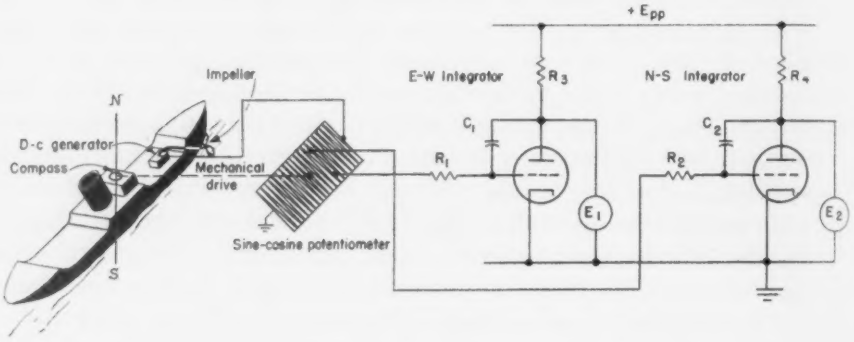


FIG. 1. Simple dead-reckoning indicator (DRI). The ship's compass connects directly to the sine-cosine potentiometer, which is supplied with a potential proportional to the ship's speed from the impeller log. The N–S and E–W components of the ship's motion are separately integrated in "Miller" integrators giving voltages E_1 and E_2 proportional to the N–S and E–W components of ship travel.

drive a pen and give a trace of the dead-reckoning position—dead-reckoning tracer (DRT)—or odograph.[3]

The procedures of navigation are not changed by the availability of DRT or API data. The dead-reckoning position is plotted on a chart. The navigator then studies the chart, selects a likely object for identification, determines whether he can observe this optically, and then attempts to locate the object visually. After several objects have been located, a visual fix may be obtained and the dead-reckoning data corrected in the usual manner. A similar procedure is, of course, employed

[1] This sine-cosine potentiometer consists of a uniform winding on a flat card. Two or usually four brushes are movable with respect to the card. See Radiation Laboratory Series, Vol. 17.

[2] A description of this integrator, a "Miller" circuit, is given in Vol. 19, Chap. 19, Radiation Laboratory Series.

[3] "Automatic Map Tracer for Land Navigation," by O. J. Faustman, Electronics, 17, 94 (1944).

in using the dead-reckoning data to identify radio beacons or stars for astronomical observation.

Visual identification of objects displayed upon a radar screen is much more difficult. Although range is much more accurately indicated than by direct observation, the range and azimuth resolution in most radar sets is not yet sufficient to resolve clearly those objects which we are accustomed to recognizing by direct viewing. For example, one may recognize a town visually by the character of the dwellings, by whether

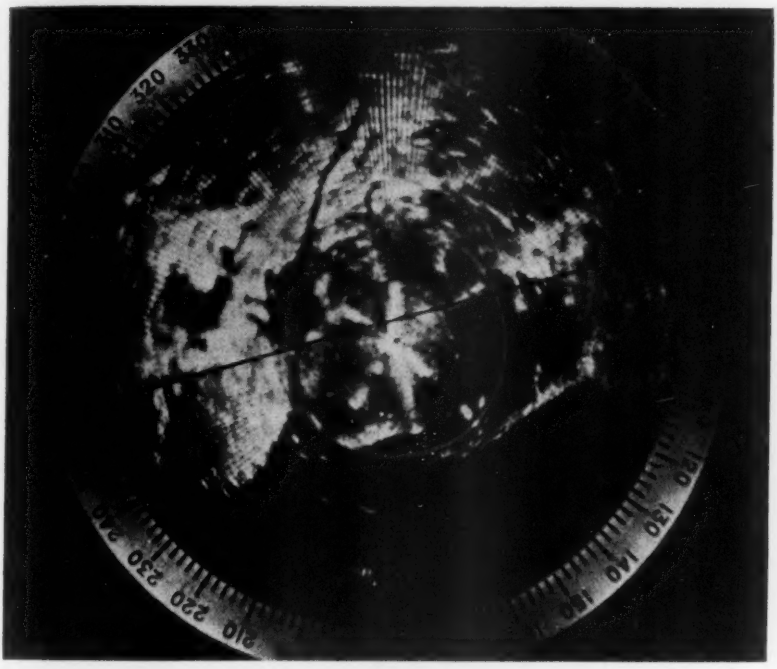


FIG. 2. Radar oscilloscope photograph showing towns, river, islands, etc. The photograph was made at high altitudes using a typical radar, AN/APS–15. The difficulty of object identification is apparent.

a highway is concrete or macadam, by whether the railway is single or double-track, etc. These identification methods are not yet possible with radar. On the other hand, radar has a much greater range and gives a much clearer picture at great ranges than does direct viewing, and therefore small-scale displays are often employed which cover a much larger area than could be covered by direct vision. Objects of importance on these displays are often the configurations of towns, mountains, lakes, and rivers. Figure 2 indicates a characteristic configuration of a river and several towns as seen on the cathode-ray-tube of a typical airborne radar (AN/APS–15).

On closer approach, smaller objects may be used for identification, especially small islands in the harbor or either one of the two bridges of Fig. 3. In addition, certain portions of the town are distinguishable, but not on a scale comparable with that obtained visually. Higher resolution radar clearly indicates distinctive configurations on a larger scale. For example, Fig. 4 has been taken with a higher resolution radar system operating at a much lower altitude, and the George Washington

FIG. 3. Radar oscilloscope photograph taken at a lower altitude showing San Francisco and details of the harbor. The clarity is greater than that of Fig. 2, but not yet adequate for the identification of small objects within the city. Mountain ranges are, however, clearly shown at the lower left portion of this photograph.

Bridge, the Hudson River, and Central Park, New York, are clearly shown as are many of the streets. Nevertheless, identification is still on a gross scale; i.e., Central Park was not identified because of the green trees or because of its relation to the Chrysler Building. Furthermore, detail comparable with that of this picture is difficult to obtain at higher altitudes.

Operational experience in the use of radar has established the necessity for accurate dead-reckoning as an aid in radar navigation, first to

identify a particular city and finally to identify a particular object within it, for example, for the purposes of bombing. In most combat aircraft operations carried out during the war, the dead-reckoning process was carried out laboriously by means of range and bearing "fixes" starting from a recognized point of departure and continuing step by step using dead-reckoning data to assist in the identification of

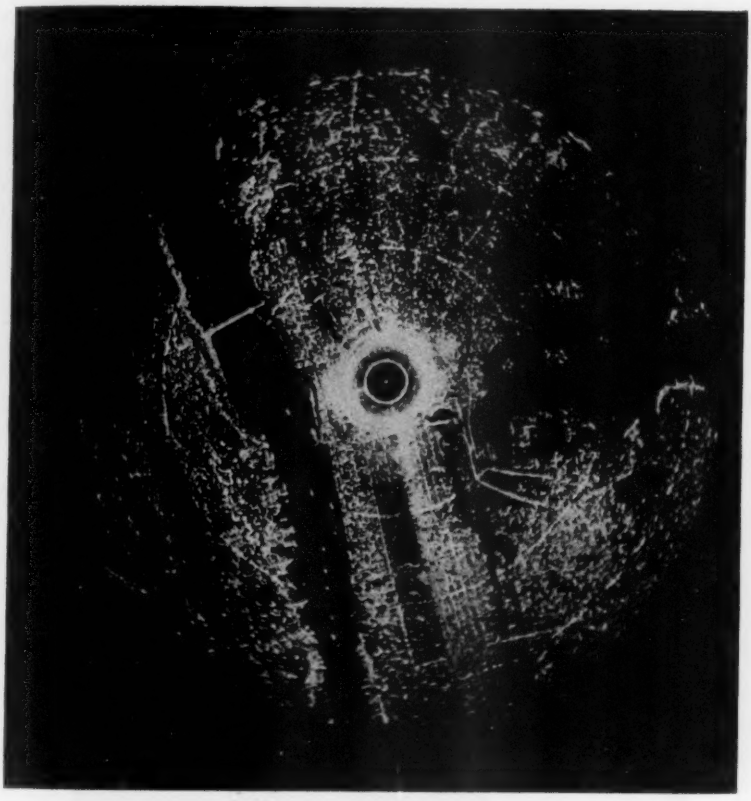


FIG. 4. A high-resolution radar oscilloscope photograph of New York City. The George Washington Bridge, the Hudson River, the docks and Central Park are clearly outlined. The lower altitude and higher resolution gives a major improvement in clarity of the picture.

a particular point, correction of the dead-reckoning data, etc. Towards the end of the war some API's were available and were of considerable assistance to the navigator.

Another important problem of air navigation which is not associated with the identification problem but which is an important part of the dead-reckoning problem is wind finding. Optically this is usually found as drift angle from the drift sight, and by taking two drift angles on different courses or timing the approach of an object, both drift angle

and ground speed may be determined if the airspeed is known. These data are readily converted into wind by means of the Army E6B computer or the Navy Mark V Plotting Board (see Fig. 5). The proper drift angle and ground speed for different courses are also readily computed. Wind may also be found by taking successive fixes upon a particular object, plotting them on a chart to obtain ground track and ground speed. If the compass course and air miles are plotted on the same chart, the line closing the figure is, of course, the wind vector. Lately an improved method for determining the ground track of an

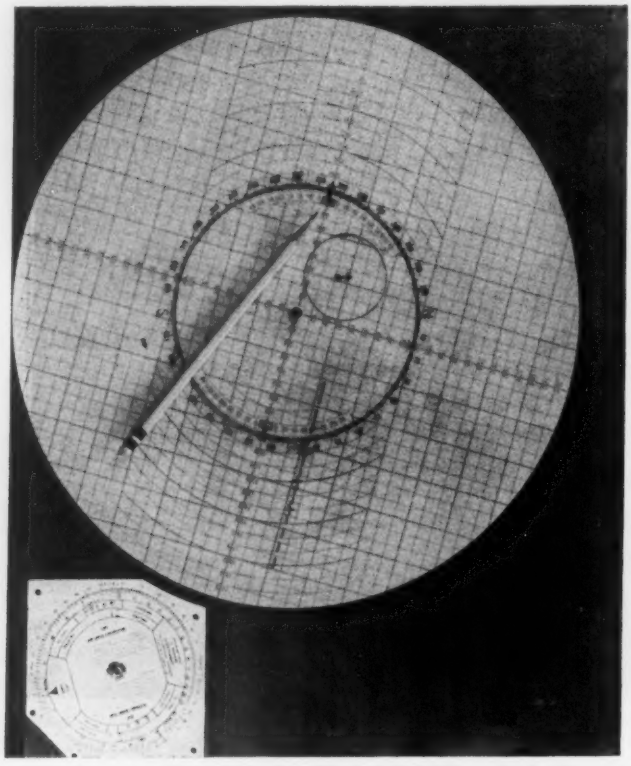


FIG. 5. Photograph of Mark 5 Plotting Board. These computers are aids in the navigator's computation of drift angle and ground speed.

aircraft in a fraction of a minute has been carried out with simple radar systems [4] by means of a doppler effect. Nevertheless, determination of wind and its conversion into drift angle and ground speed on a particular course is one of the tasks that a navigational computer should eliminate.

1.2. *The Interconnection of Dead-reckoning and Radar Data.* In 1943 at the start of the operational use of radar by the 8th Air Force, interest

[4] Radiation Laboratory Series, Vol. 20, Chap. 2.

in the radar navigational problem was stimulated at the Radiation Laboratory, and the experience and emphasis of the RAF on the importance of dead-reckoning methods in radar navigation led to approximately simultaneous developments of automatic means for the interconnection of dead-reckoning and radar data. In this country the development was termed "GPI" [5] and a similar development occurred in England.[6] It is the object of these systems to present an index on the radar display which continuously indicates the dead-reckoning position of an identifiable object. Thus, a straightforward comparison of dead-reckoning and radar data on the screen of the cathode-ray tube leads to a great reduction of the navigator's use of charts for plotting and computing and serves as an important aid in the identification of a particular object.

The dead-reckoning position is usually computed not in terms of the position of the aircraft but in terms of the expected position of an identifiable object. This dead-reckoning position is indicated by a crosshair on an oscilloscope as shown in Fig. 6. If the dead-reckoning information is correct, this crosshair will be nearer to the particular object chosen than any one similar to it. The displacement between the crosshair and the identified object is then the error of dead reckoning and may be reduced to zero by setting the object to the crosshair. In addition, these computers give dial indication of dead-reckoning position, permit a ready determination of wind by a simple tracking procedure, and give a direct indication of the course and time of arrival to any object within a reasonable distance of the aircraft as will be discussed later.

Use in Ship Navigation. Although the discussion above has centered upon the problems of object identification in aircraft navigation by radar, the discussion also applies to the problem of ship navigation where, although the speeds are considerably less, the accuracy required is considerably greater. These principles apply especially to the accurate pilotage of ships through narrow channels, where high precision is required and where an error in identification of a radar echo could not be tolerated.

A schematic diagram of an interconnection of radar and dead-reckoning data is indicated in Fig. 7 and is based upon a method of resolution and integration similar to that indicated in Fig. 1. This method lacks the precision required for a number of applications, but it is presented here for two reasons—first, it permits an explanation of the use of this technique in both ship and aircraft navigation based upon essentially the same computer elements. Secondly, this method avoids the discussion of many complicated and obscure methods which were re-

[5] Radiation Laboratory Report No. 63-12/6/43, "Proposed GPI System," Britton Chance. Also unpublished work of G. E. Valley and L. N. Ridenour.

[6] Unpublished work by A. Uttley and F. C. Williams of TRE.

quired to obtain higher precision by avoiding the errors of the cathode-ray-tube display.[7] Provided the inaccuracies of the cathode-ray-tube display could be rectified, the method used in the following examples has definite possibilities for precise navigation and has already been used in a TRE navigation system. As in Fig. 1, the speed obtained from an

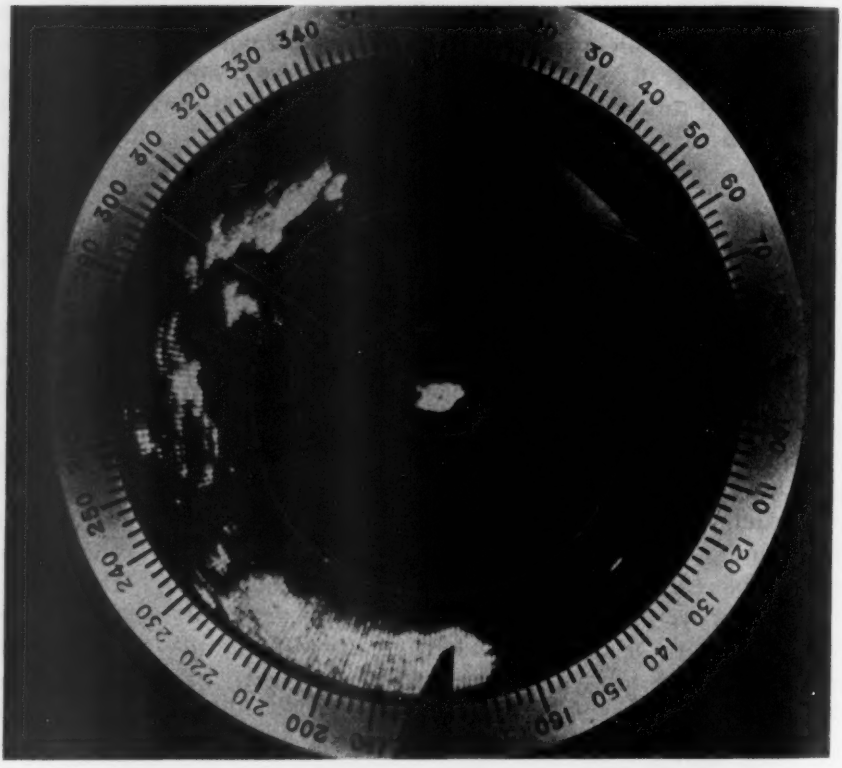


FIG. 6. A typical radar oscilloscope display of a crosshair generated by dead-reckoning data set near a distinctive radar echo. The proximity of the crosshairs to this particular echo distinguishes it from other echoes as the desired echo.

impeller log and the course obtained from the compass are resolved into north-south and east-west components by a sine-cosine potentiometer. These voltages are then integrated and connected to the perpendicular plates of the cathode-ray oscillograph (radar indicator) to move the origin, A, of the display in accordance with the motion of the ship. If

[7] An accurate navigational computer constructed for an experimental test of these principles in aircraft navigation employs electromechanical integrators and synchos for rectangular to polar coordinate resolvers. The method of operation and sources of error are presented in "GPI—An Automatic Navigational Computer," W. J. Tull and N. W. MacLean submitted to J. F. Inst.).

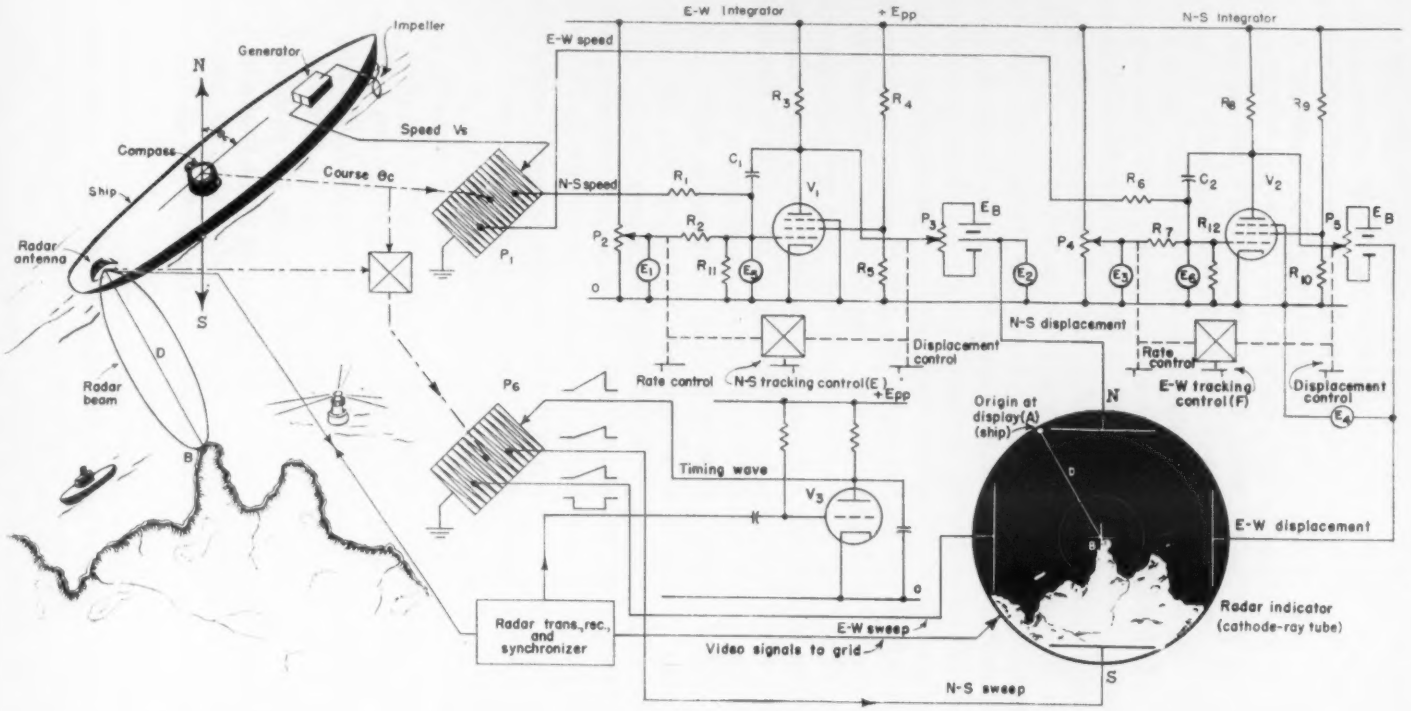


FIG. 7. Schematic diagram indicating the interconnection of radar and dead-reckoning data. The size of the ship is, of course, exaggerated, and all the circuit components, including the radar indicator, would, of course, be carried on board the ship. The plan view of the coast line is duplicated in the radar indicator (PPI), and the crosshair represents the dead-reckoning position of the point of land (B) as computed by the apparatus.

the displacement controls were adjusted initially at the point of departure to indicate the true position of the ship, then subsequent positions of the ship will be traced out on the face of the cathode-ray tube by the spot, A. In addition, voltmeters E_2 and E_4 indicate the numerical value of the distance from the point of departure. Known corrections for current may be entered by means of the rate controls indicated in order to increase the accuracy of the dead-reckoning indication.

The radar data may be displayed upon this same indicator by creating a PPI display about the moving origin, A. A conventional method is indicated here (ME PPI) [8] in which the mechanical position of the scanning radar beam is referred to north by means of a differential connecting to the compass. The output of this differential turns a sine-cosine potentiometer which resolves a triangular timing wave generated in V_3 in synchronism with the transmission of the radio frequency pulses. The north-south and east-west components of the timing wave are then connected to the other pair of deflection plates of the cathode-ray tube. The received echoes are connected to the grid of the cathode-ray tube giving an intensity-modulated display. If the point of departure, i.e., the point at which the dead-reckoning system was set into operation, was the point of land B, the ship will have moved away from this point of land a distance D indicated by the motion of the origin of the display to point A. The point of land B will therefore still appear at the center of the display providing the dead-reckoning information was correct and will continue to do so as long as the dead-reckoning data are accurate and the circuits are operating within their limitations.

Aided Tracking. If, however, the point B does not remain in contact with the crosshair at the center of the display due to currents which are not accounted for or due to errors in the compass or speed information, the tracking controls E and F may be employed to reset point B to the crosshair, thus reducing the displacement error to zero and at the same time introducing an appropriate rate correction to account for the errors. The tracking method indicated in this diagram is called "aided tracking" [9] and depends upon an alteration of displacement and rate at a fixed ratio which has the dimensions of seconds and is called the "time constant." If the tracking controls are used to reset point B to the crosshair at intervals equal to the time constant, then the rate correction entered by the differential gear will exactly counteract that due to the errors. If the error is due to an ocean current, then the rate added indicates at E_1 and E_3 the magnitude of the components of this ocean current.

Memory-point Tracking. Some inconvenience may be encountered in using this particular method of tracking, since the rate is only properly

[8] See Vol. 22, Radiation Laboratory Series.

[9] See Radiation Laboratory Series, Volume 20, Chapter 7.

corrected if the corrections are made at a period equal to the time constant of the aided tracking system. This may be disadvantageous in radar systems which have a long scan period which is not equal to the time constant of the aided tracking system or in cases where the radar echo may fluctuate and the time at which the setting is made may be dictated by the reappearance of the echo. If, however, the time constant of the aided tracking system is made a linear function of time, the operator may make the setting at any desired time. This method is termed "memory point tracking."[10] The displacement error is made zero by turning the displacement knobs so as to cause the crosshair and the desired echo B to coincide. As indicated in Fig. 8, the battery E_B of Fig. 7 is modified to include resistors R_1, R_2, and R_3. Resistor R_3 is controlled by a clock so as to increase the potential across P_3 or P_5 linearly with time. When R_3 is zero, the displacement control is ineffective and the time constant is zero. At the initiation of the tracking operation, the variation of R_3 by clock C will increase the effectiveness

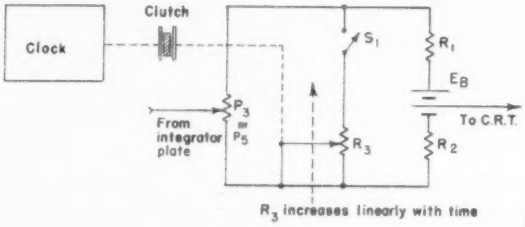


FIG. 8. Modifications of the battery voltages E_B of Fig. 7 required for memory point tracking. The clock is started when S_1 is closed and increases the time constant of the tracking system linearly with time.

of the displacement control linearly with time giving a corresponding increase of the time constant. Mathematical analysis readily indicates that the exact value of the rate is entered regardless of the time at which the setting is made.

The operation of memory point tracking systems is as follows. Initially S_1 is open, and the displacement controls in both coordinates are rotated to cause coincidence of the crosshair and the desired echo B of Fig. 7. When the displacement error is made zero, switch S_1 is closed defining a time termed "the memory point." The north-south and east-west tracking controls are then rotated in order to maintain any displacement of the target and crosshair at zero. After this operation has proceeded for a minute or so, an accurate value of the north-south and east-west drift will be established, regardless of the time at which the setting is made. In usual practice the clock operates for 5 or 10 minutes. The final value of the rate remains set into the integrator and need not be redetermined until conditions change.

[10] Radiation Laboratory Series, Vol. 20, Chap. 7.

1.3. *Relative Movement of Two Ships.* The usefulness of this sophisticated method of rate determination is not apparent in the diagram of Fig. 7 where currents are likely to be negligible for ships of a reasonable speed. But this method of memory-point tracking may be of extreme usefulness in problems involving the relative motion of two ships as indicated in Fig. 9 where point of land *B* of Fig. 7 has been replaced by ship *S*. The adjustment of the displacement controls until *S* coincides with the crosshair gives the north-south and east-west components of the distance of that ship. Furthermore, tracking the ship by either the aided tracking method of Fig. 7 or the memory-point tracking method of Fig. 8 gives the north-south and east-west components of the velocity of *S* with respect to *A*. Given the components of both the distance and speed, the probability of collision of the two vessels could easily be detected, or, if desirable, computations can be made which would give the course on which such a collision would occur

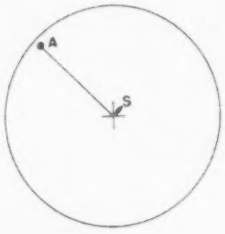


FIG. 9. A representation of the determination of the relative motion of two ships by this apparatus. Ship (A) is carrying out the tracking operation and ship (S) is being tracked.

and the time at which it would occur. There are, however, limitations of the accuracy of the data obtainable from scanning radar systems and extremely high accuracy requires nearly continuous data.

1.4. *Aircraft Navigation.* The greatest need and use for this navigational method has been in high-altitude aircraft where both radar and visual observation are handicapped by the relatively large distance of the nearest fixed object (5 to 7 miles). In addition, low temperature, cumbersome oxygen equipment, and fatigue render the navigator much less efficient than he would be on the ground. For satisfactory performance under such adverse conditions, it is desirable to simplify and to mechanize as many of the navigational procedures as possible. Therefore, the automatic dead-reckoning computer interconnected with radar as described above is extremely useful not only in the correlation of dead-reckoning and radar information for identification of fixed points but also in wind finding and in the prediction of course and distance to a destination.

The two-dimensional solution represented in Fig. 7 is not directly applicable to the aircraft case, since a three-dimensional problem is in-

volved here. It is, however, relatively simple to convert the three-dimensional aircraft problem to its projection on the horizontal plane or ground. This is, in fact, what is desired, since air navigation is referred to the surface of the earth immediately below the aircraft. The instrumentation represented in Fig. 7 therefore applies to this case provided two alterations are made. First, the radar must represent a picture of the ground for reasonable distances beneath the aircraft, and the required shape of the antenna pattern is indicated in Fig. 10 and is termed the $\csc^2 \theta$ pattern.[11] A second alteration is required to convert

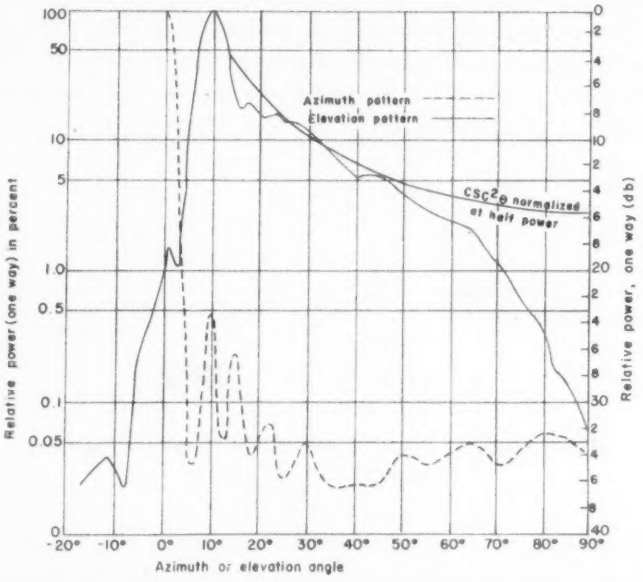


FIG. 10. A radar antenna pattern required for aircraft navigation. This is often termed a $\csc^2$ pattern.

the radar picture from one representing slant range to one representing ground range. As indicated in Fig. 11, the radar system measures slant range ρ, and any particular value of slant range may be converted into ground range by solution of the triangle $\rho = (R^2 + H^2)^{\frac{1}{2}}$. This problem has stimulated the development of a number of ingenious methods for triangle solutions. The most difficult problem, that of solving instantaneously for all values of ρ, is essential for the conversion of the data displayed on the cathode-ray tube. A simple solution to this difficult problem is indicated in Fig. 12. Curve (A) of Fig. 12a represents the sweep used in the example of Fig. 7, i.e., the linear portion of an exponential wave initiated at the time of transmission of the r-f pulse of

[11] Samuel Silver, JOURNAL article on Microwave Transmission Lines and Antennas (not yet published). See also Vol. 12, Radiation Laboratory Series.

the radar system by the circuit of Fig. 12b. This waveform therefore gives a display in which the spot position is directly proportional to time or slant range. If, however, the time of initiation of the display waveform is delayed to a distance corresponding to the aircraft altitude and a hyperbolic wave (B) is generated, an exact and instantaneous solution to the equation $R = (\rho^2 - H^2)^{\frac{1}{2}}$ is obtained.[12]

The delay in the time of initiation of the hyperbolic wave is easily adjusted by obtaining a sweep trigger from the radar synchronizer which is delayed with respect to the time of transmission of the r-f pulse.[13] The hyperbolic waveform itself can be closely approximated by the simple resistance-capacitance network indicated in Fig. 12c. In actual practice the instantaneous rise of the hyperbolic wave at its time of initiation is impractical to obtain, and therefore the delay in its initiation is made slightly less than the altitude, roughly 0.9 H.[14]

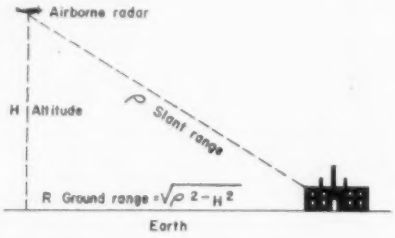


FIG. 11. Representing the conversion of slant range ρ to ground range, R, at an aircraft altitude H.

With the change of the radar antenna pattern and the correction of the display, we may proceed with the discussion of the elements of the schematic diagram of Fig. 7 which are applicable to aircraft navigation. First, the previous discussion about the continuous indication of dead-reckoning position and its verification by correcting the error between the dead-reckoning position and that of a fixed point is extremely useful in aircraft navigation. But the aided or memory point tracking mechanism assumes much greater importance in aircraft navigation than in ship navigation, for wind in excess of 150 knots must occasionally be taken into account in high-altitude flying. The tracking procedure is therefore carried out more frequently in order to detect any variations in the wind, and the values found in this manner are represented on meters E_1 and E_3 and automatically influence the computation of the dead-reckoning position.

[12] See Vol. 19, Chap. 8, Radiation Laboratory Series.

[13] Circuits for this purpose are described in detail in Vol. 19, Chap. 13, Radiation Laboratory Series.

[14] See Radiation Laboratory Series, Vol. 19, Chapter 8.

With winds as large as this, the ground track and ground speed often differ appreciably from the air track and airspeed, and it is therefore desirable to represent continuously the former values in order to facilitate precise navigation to a particular point and accurate prediction of the time of arrival there.

A usual display of ground track, θ_g, and ground speed, V_g, may be obtained by alternating the display of the radar picture with the display

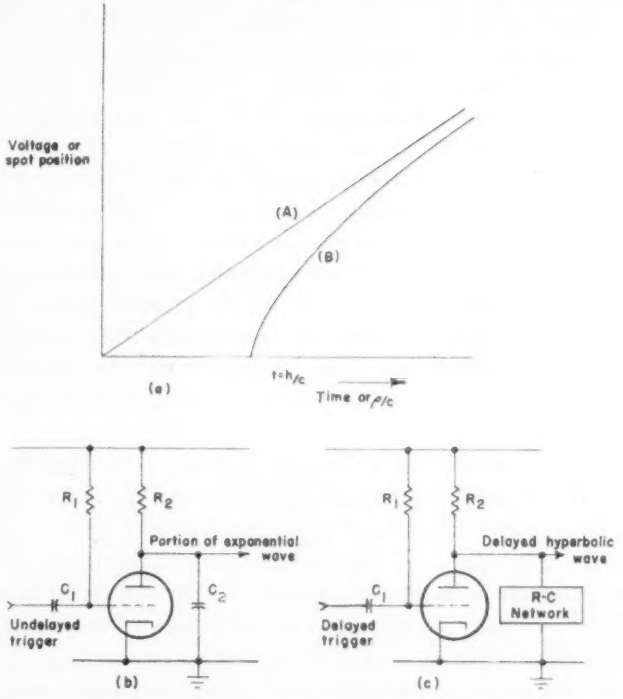


FIG. 12. The use of a delayed hyperbolic waveform for solving the expression $R=(\rho^2-H^2)^{\frac{1}{2}}$. Fig. 12a represents the linear sweep (A) employed in Fig. 7 and a delayed hyperbolic sweep (B) which is started at a time delay corresponding to the aircraft's altitude. Figure 12b represents the waveform generator for obtaining a triangular wave. Figure 12c represents a waveform generator for obtaining a delayed hyperbolic wave.

of the voltages E_5 and E_6. If the display is connected to E_5 and E_6, the position of the craft (A) will be displaced an amount equal to the components of ground speed, and the resultant displacement will represent the ground speed. Furthermore, the direction of a line through this displaced spot and the former position of (A) will represent the ground track. If, however, E_5 and E_6 are converted into alternating voltages as indicated in Fig. 13, a line is drawn on the display whose direction is the ground track and whose length is the ground speed. More satisfactory for the purposes of navigation, however, is a line whose length

is proportioned to the scale of the display to indicate the distance the aircraft will travel in a certain time, for example, 5 or 10 minutes. If desired, this may be used as a scale in determining the time of arrival of the aircraft at any particular point. Furthermore, alteration of the course of the aircraft to cause the ground track line to pass through any particular point will ensure precise navigation to that point.

Considerably rarer in the case of aircraft is the problem of obtaining precise information on the relative speed of another aircraft. But in certain cases it may be desirable to obtain the relative speed of another aircraft with respect to the ground in order that aircraft may be guided through a safe navigational procedure. This difficult problem may be readily solved by these techniques, since the apparatus already described refers the motion of the first airplane to ground. A second similar computer may be employed to obtain the relative motion of the two aircrafts much as was indicated in Fig. 9. Subtraction of the data from these two computers would, therefore, give the motion of the second aircraft with respect to the ground, and from these data all necessary computations with regard to its ground speed and ground track can be made, and, in fact, its dead-reckoning position may be represented on a cathode-ray-tube display and the prediction of its course and time of arrival at a particular destination carried out as already described.

1.5. *Aircraft Control from a Ground Station.* Another use of the important features of prediction made possible with this type of instrument is found in the control of aircraft from ground stations. Although the problems of identification by dead-reckoning position are no longer important, the ground controller of aircraft is often faced with the problem of the precise navigation of the aircraft to a remote destination in terms of course and time of arrival at that destination.

This procedure can be readily carried out with fire control radar,[15] but radars operating over longer ranges and carrying out air warning functions at the same time must scan continuously and, because of their long range, must scan slowly [16] (scan periods of 30 seconds). A modification of the computation mechanism of Fig. 7 for this purpose is relatively straightforward. Since the controlled aircraft is friendly and the control requires communication, the airspeed and compass courses are known since they are part of the control instructions. These are, therefore, entered into the computer manually (or in more sophisticated systems by continuous radio relay from the aircraft). These data are, of course, an important first approximation to the travel of the aircraft, since the only quantity left to be determined is that of wind, which at lower altitudes will not usually exceed 50 knots. The remainder of the

[15] See "The SCR584 Radar," *Electronics*, **18**, 104 (1945).

[16] See Radiation Laboratory Series, Vol. 1.

tracking and integration functions are carried out as before and displacement corrections are entered until the aircraft echo falls on the crosshair. Aided or memory point tracking is then initiated and the components of the wind are established. These data may be displayed upon the cathode-ray tube by electronic switching by the method indicated in Fig. 13 with the exception that the origin for the ground track line should, of course, be the aircraft or, to a first approximation, the crosshair. This simply means that the electronic switching includes the elimination of the north-south and east-west displacement voltages. The destination of the aircraft may be marked on the display by another

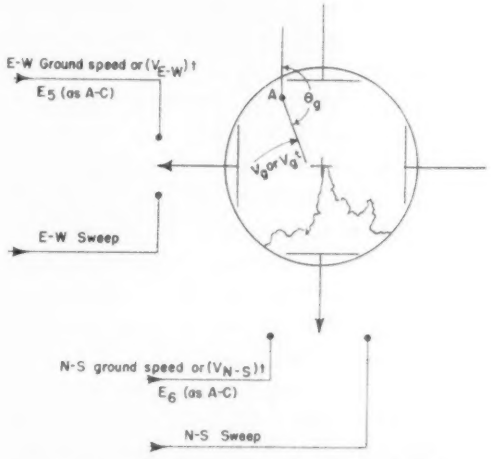


FIG. 13. Modifications to the cathode-ray-tube display of Fig. 7, permitting the alternate display of a ground track and ground speed or ground distance mark. The direction of line θ_g is the ground track of the aircraft and an exact course to any object displayed upon the indicator may be steered by pointing this line towards it. The length of the line may represent ground speed or, more desirably, the distance travelled in a given time interval.

crosshair established by previous calibration or, more advantageously, may be displayed along with the aircraft echo by a simulation process termed "video mapping."[17] The control of the aircraft to arrive at this destination is carried out by the procedures of Fig. 13 except that radio communication to the aircraft is required to direct alterations of course which will cause the ground track line to pass through the desired destination.

The particular instrumentation of Fig. 7 and 13 is especially suitable to slowly scanning radar. If the received signals are displayed upon a long-persistence-cathode-ray tube, the persistent echoes may be reset to the fixed crosshair even though they are displayed for 1/30 second every 20 seconds.

[17] See Radiation Laboratory Series, Vol. 2.

Summary. A simplified method for the interconnection of radar and dead-reckoning data has been presented and used to illustrate the application of this principle to ship and aircraft navigation problems. This interconnection facilitates the interpretation of radar data and increases the accuracy of the dead-reckoning data. Furthermore, the prediction of time of arrival of a craft at a stationary or a moving object is readily computed.

GPI—AN AUTOMATIC NAVIGATIONAL COMPUTER.

BY

W. J. TULL[1] AND N. W. MAC LEAN,[2]

Radiation Laboratory,[3] Massachusetts Institute of Technology.

PART I.

THE FUNDAMENTAL GEOMETRY OF THE GROUND POSITION INDICATOR.

Ground Position Indicator (GPI) is a term commonly used to denote equipments which indicate continuously the present position on the earth's surface of those vehicles in which they are carried. In general, these devices give present position by integrating the vehicle's velocity over the time it is in motion. The indication of position is usually given on present-position dials as either the total distance away from a point of origin or as the latitude and longitude of present position. The applications and techniques of using equipment of this type have been discussed by Chance in separate papers.[4]

There are three phases to the process of continuous presentation of ground position, first the determination of fix; second, the determination of ground rate; and third, the determination of ground course. The most straightforward GPI would be capable of measuring and using each of these factors directly, and, indeed, the trend is in that direction. However, present devices usually employ techniques involving the summation of a number of components in order that each of the three factors necessary for navigation can be determined.

The particular device described in this article illustrates one way in which a ground position indicator can be designed to make effective use of the information available from a PPI type radar. This device was primarily designed for aircraft. However, in general, most of the statements made here are true regardless of the type of vehicle. This computer receives fix data from the radar and compass, and rate information from a true-airspeed meter. From these data it computes the wind and provides ground speed information for the integrators. In addition to presenting as numbers the total distance traveled, this GPI indicates the heading to be steered in order that a particular course may be followed. It also presents the position of the aircraft relative to any

[1] Now at General Precision Laboratories, Inc., Pleasantville, New York.

[2] Now at Illinois Bell Telephone Co., Chicago, Illinois.

[3] This paper is based on work done for the Office of Scientific Research and Development under contract OEMsr-262 with the Massachusetts Institute of Technology.

[4] Britton Chance, "The Interconnection of Dead Reckoning and Radar Data for Precision Navigation and Prediction," JOURNAL OF THE FRANKLIN INSTITUTE, this issue, pp. 355-372.

landmark, when an electronic index (or crosshairs) is placed in coincidence with the radar signal from that landmark as it appears on the radar scope. Furthermore, the time necessary to reach the designated point, flying on the prescribed heading, is given.

Fix Determination

Fix is a navigator's term implying the determination of position relative to some known reference or landmark. Position is established in this computer by making three measurements. The first is a determination of the difference in altitude between the aircraft and the landmark or reference; next, the slant range or straight-line distance between the aircraft and reference is measured; and third, the direction of the landmark relative to the vehicle is determined. Information entered into the determination of fix is shown in Fig. 1. The value for

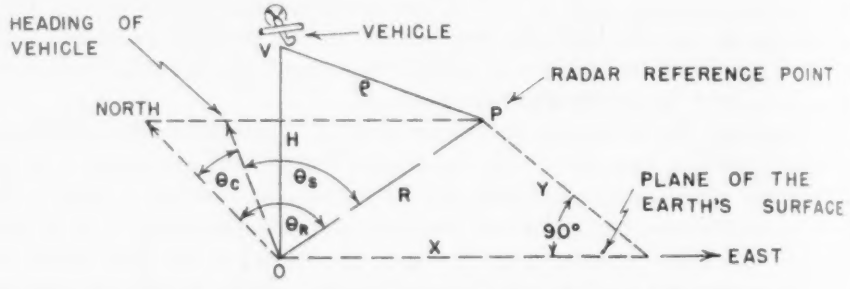


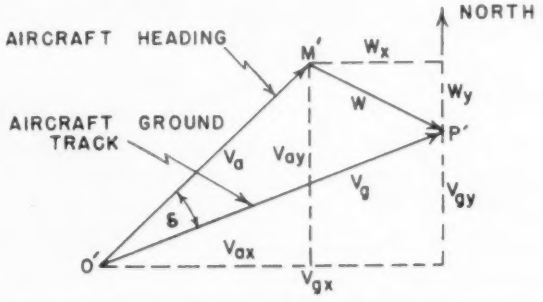
FIGURE 1. GEOMETRY OF FIX.

altitude (H) is first set into the computer by making an electronic range marker coincide with the first radar signal appearing on the radar PPI. This measures distance to the ground, or altitude. Secondly, the north-south and east-west components of fix mileage, Y and X, are adjusted until the crosshairs appear on the reference P. When this has been done it is possible to read from dials the altitude of the aircraft above the ground and its ground position with respect to the reference. Ground position is shown in rectangular coordinates by two dials, one corresponding to X miles in the east-west direction, the other to Y miles in the north-south direction. From this point on, all of the GPI computations are made in a plane parallel to the earth's surface, the altitude (H) factor being used only to convert slant-range radar data to GPI ground range information.

Rate Determination

The ground rate of the vehicle is determined by vector addition of the true airspeed, V_a, and the wind, W, acting upon the vehicle. This vector addition is illustrated in Fig. 2.

The components of groundspeed, V_{gx}, and V_{gy}, are used to control the rate of change in magnitude of X and Y discussed in the previous section so that the electronic index will move on the radar scope with the same groundspeed as the aircraft but in the opposite direction. As can now be seen, if the index had been placed over some radar landmark on the radar scope it would remain on that reference as long as the values taken for the rates were correct and the coordinate systems used for rate and fix components were the same. If the aircraft should



V_a = True Airspeed Vector	V_{gx} = E-W Component of V_g
V_g = Ground Speed Vector	V_{gy} = N-S Component of V_g
W = Wind Vector	V_{ax} = E-W Component of V_a
δ = Drift Angle	V_{ay} = N-S Component of V_a
W_x = E-W Component of Wind	W_y = N-S Component of Wind

FIGURE 2. GEOMETRY OF RATE.

change heading, V_{gx} and V_{gy} would continue to represent the coordinate sum of V_a and W vectors, and the crosshairs would even then remain on the radar landmark.

If at a time when a wind W was blowing, zero wind had been entered into the GPI, it is obvious that the index would not remain coincident with the reference. Rather V_{gx} and V_{gy} would represent components of the true airspeed (V_a) and the crosshairs would drift off from the landmark at the rate and in the direction of the wind W. In order that ground rates used by the GPI will be correct the wind must be entered into the computer. This is done by a process known as "memory point tracking." It consists of making two fix determinations, comparing the ground distance traveled with the air distance traveled and dividing their difference by the time necessary to accrue that difference. The actual procedure used by the operator consists of placing the electronic

index coincident with the landmark on the radar scope, pushing a switch, waiting until the electronic mark drifts off the landmark and then resetting it on the landmark. When this process is completed, the wind computations will have been performed by the GPI and the correct rates should cause the marker to remain coincident with the radar signal.

Course Determination

The course of the vehicle is set by placing the electronic index on the point over which it is desired to fly. This can be done in either of two ways. The first method consists of placing the index in coincidence with a signal after making a simple visual comparison of their relative positions as they appear on the radar scope. The second method per-

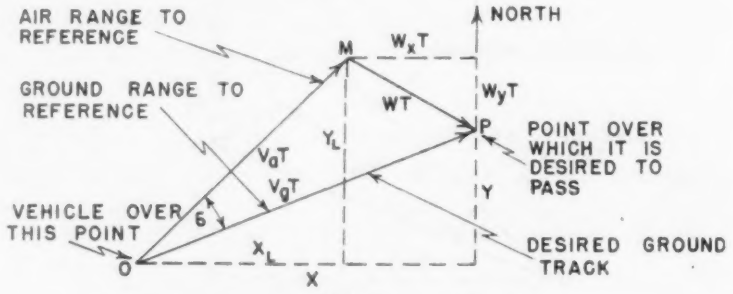

AIR RANGE TO REFERENCE
GROUND RANGE TO REFERENCE
VEHICLE OVER THIS POINT
NORTH
M
W_xT
W_yT
WT
P
POINT OVER WHICH IT IS DESIRED TO PASS
Y_L
V_aT
V_gT
Y
δ
X_L
O
X
DESIRED GROUND TRACK
V_aT = Air range to reference point = R_L
V_gT = Ground range to reference point = R
WT = Distance aircraft is blown in time T.
T = Time to travel path OP, heading constant.
Consider point M moving as time T changes, M coincides with P when T = O, aircraft heads toward M to reach point P.

FIGURE 3. COURSE DETERMINATION GEOMETRY.

forms the same function for points which do not appear on the radar scope. This method takes advantage of the GPI's knowledge of present position and the operator's ability to set the fix dials to desired future position numbers. This is discussed further in a later section titled "Identification of Radar Signals." Since the fix dials define the position of the crosshairs, the index will appear in the correct position on the radar scope whether a radar signal is there or not. The geometry of GPI course determination is illustrated in Fig. 3.

From Fig. 3 it can be seen that all factors are known from previous GPI computations except the time T. This represents the time necessary to reach point P at the present airspeed and with the present wind if a heading is taken such as to cause the ground track of the aircraft to pass directly through this point.

Triangle *POM* is similar to the triangle $P'O'M'$ of Fig. 2, since their sides are proportional, and the proportionality constant is the time T. Since both R and V_g are known, T can be determined if R is divided by V_g or, as in the computer described here, if R_L is divided by V_a. This time may be indicated on a meter and used by the operator to determine his time of arrival at destination.

PART II.

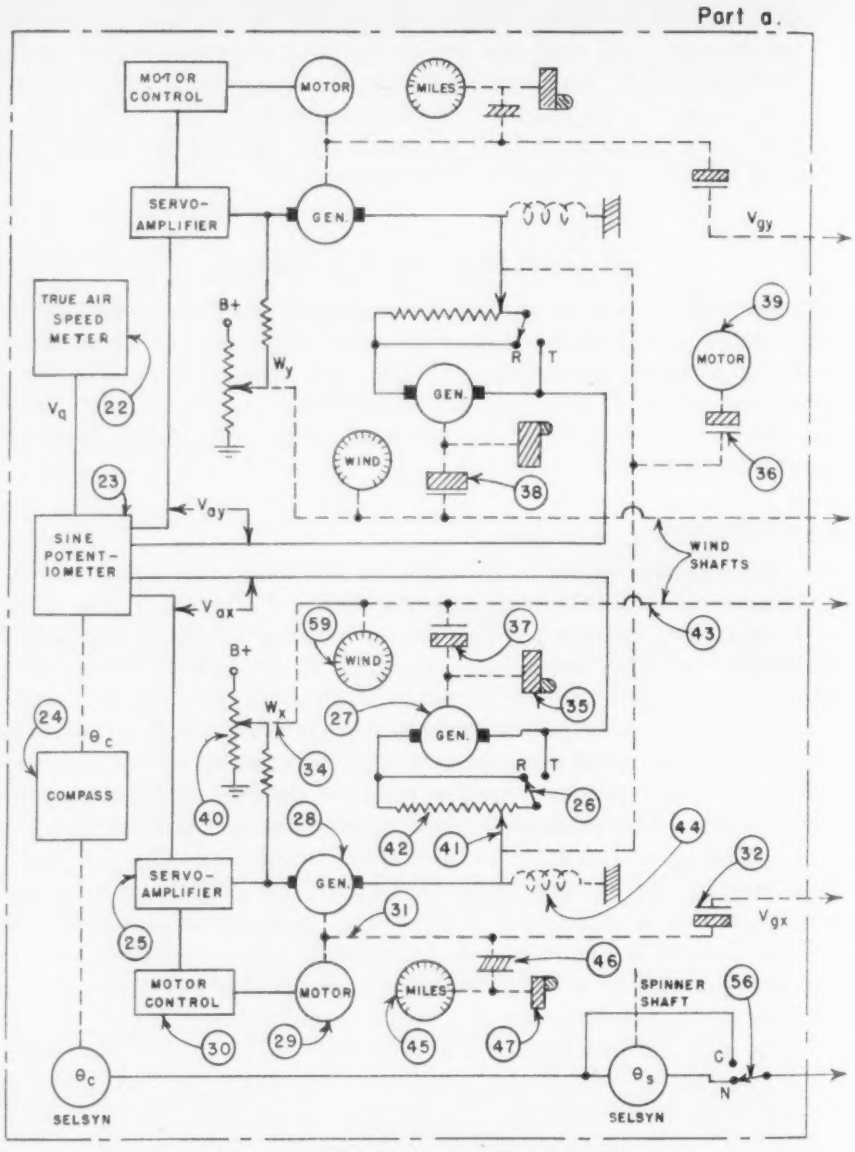
THE MECHANISM BY WHICH GPI COMPUTES.

In the following step-by-step discussion of the GPI computer frequent reference will be made to Fig. 4. This figure has been divided into three sections containing (*a*) the rate mechanisms, (*b*) the fix mechanisms, and (*c*) the course mechanisms. In this figure dashed lines represent mechanical connections, and solid lines, electrical connections.

Fix Computation

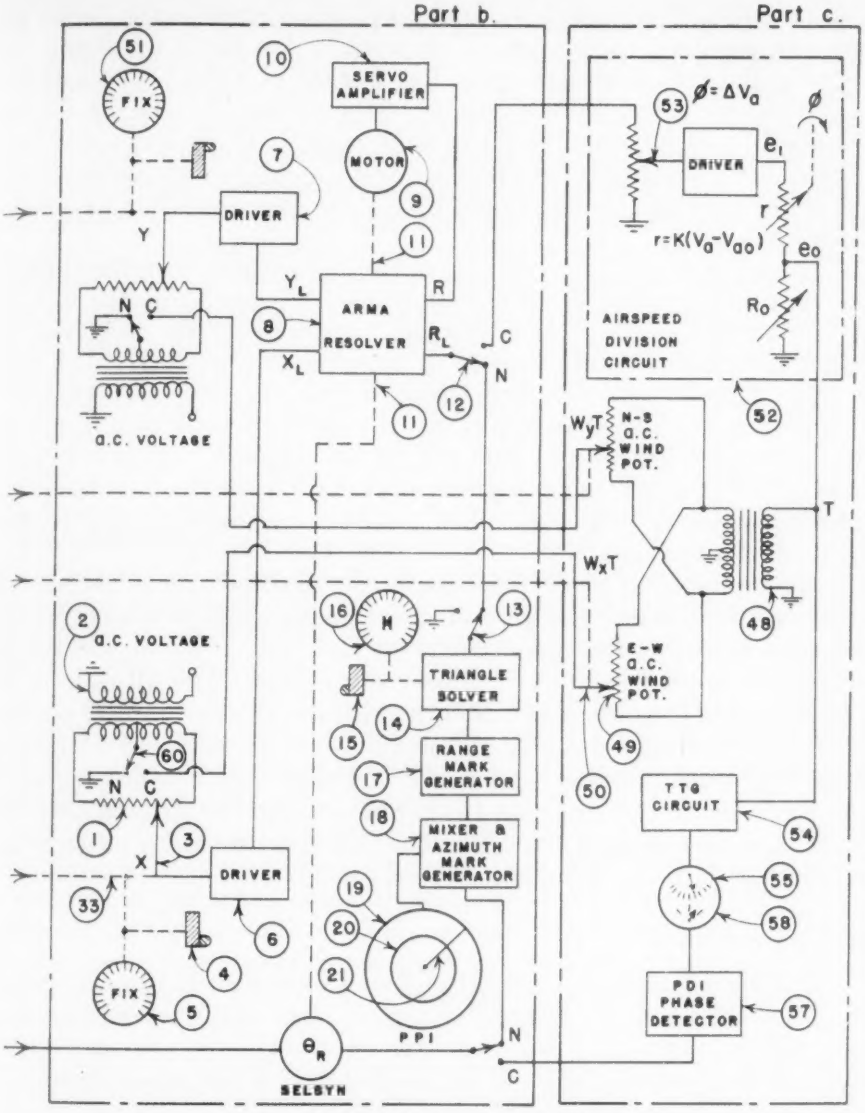
Fix measurements are made with the function switch (marked N-C for navigate-course) in the navigate position. Referring to Fig. 4, part *b*, it is seen that helipot (1) has an a-c voltage across it supplied by transformer (2), the center tap of which is grounded. The voltage output of the helipot will vary from full voltage to zero at the center to full voltage again as the potentiometer arm (3) sweeps across the helipot. It should also be noted that there is a phase reversal of voltage as the potentiometer arm passes over the center of the helipot (voltage passes through zero). The shaft of the helipot (1) has been fitted with a knob (4) and a dial (5). If a scale factor of some number of volts per nautical mile output of the helipot is decided upon, the dial (5) can be given markings which indicate the helipot arm position in nautical miles. Since the helipot is linear, the dial markings will be uniform. At this point, it is possible to say that an adjustment of dial (5) to any number will result in the presentation of a proportional voltage, X, to the driver (6). The dial calibration for the computer is such that the voltage from ground to one end of the helipot represents twenty nautical miles. The driver (6) is an impedance matching device with an input-output ratio of 1:1. The input to the other driver (7) is managed in the same fashion as described for driver (6). The voltage X_L from driver (6) represents at all times the algebraic sum of the E-W components of distance to be introduced to the Arma resolver (8). In this instance, the voltage X_L consists only of the distance X shown in Fig. 1. The two a-c voltages representing X_L and Y_L are the inputs to the Arma resolver (8).

The Arma resolver is a device used to perform vector addition of a-c voltages. It has two stator windings displaced ninety mechanical de-



GPI FUNCTIONAL DIAGRAM
FIGURE 4-A

grees from one another and two rotor windings similarly displaced. If the two stator windings are excited by voltages X_L and Y_L respectively, and if then the rotor is turned until the voltage output of one of its coils is zero, the output of the second rotor coil will be the resultant of the two input voltages. Also, the position of the rotor shaft will then represent the angle whose tangent is X_L/Y_L. In practice, the shaft of



GPI FUNCTIONAL DIAGRAM
FIGURE 4-B,C

resolver (8) is turned by a motor (9) under control of servo amplifier (10) until the voltage output R of the resolver is zero. Under this condition, the other resolver output voltage R_L is equal to the square root of the sum of the squares of X_L and Y_L.

The voltage R_L is applied through switches (12) and (13) to the altitude triangle solver (14). The triangle solver also has applied to it a voltage in quadrature with R_L controllable by the altitude knob (15).

The potentiometer turned by knob (15) has a scale factor (miles per volt) proportional to the rest of the system, but for convenience, the altitude dial (16) markings are in feet instead of miles. The output ρ of the triangle solver is the resultant of the voltage R_L and the altitude voltage H, and its proportional to slant range. The voltage ρ enters a range mark generator (17) to produce voltage pulse which in turn enters the mixer (18) and thence to the PPI scope (19) appearing as a range circle (20).

The azimuth mark portion (21) of the index comes from the addition of three selsyn voltages. The first voltage, θ_c, represents the heading of the aircraft. The second voltage, θ_s, represents the direction the antenna (spinner) points relative to the aircraft's heading. The third voltage, θ_R, represents the Arma resolver position. With θ_s continually changing as the radar spinner turns, the azimuth mark generator produces a mark whenever the sum of θ_c and θ_s equals θ_R. This is done by causing a PPI sweep to be brightened as the spinner passes through the position where $\theta_s = \theta_R - \theta_c$. This addition can more readily be seen by reference to Fig. 1.

The intersection of the range mark (20) and the azimuth mark (21) constitutes an index, the ground range components of which are the mileages shown on the two fix dials (5) and (51), providing the proper altitude is entered into the triangle solver (14). The altitude is adjusted by first grounding switch (13) which then gives complete position control of the range mark to the altitude voltage (H), and by turning knob (15) until the range mark (20) coincides with the first signal on the PPI. Since this first signal is ground return, the altitude knob will have been turned until the dial (16) reads the true radar altitude and the voltage into the triangle solver (14) will be correct.

Rate Computation

Making reference to part (*a*) of Fig. 4, it is seen that a d-c voltage V_a taken from the true airspeed meter (22) has been resolved into components by means of a sine potentiometer (23) which turns with the shaft of the compass (24). If the sinepot (23) is properly adjusted, its two voltage outputs will be $V_a \sin \theta_c$ or (V_{ax}), and $V_a \cos \theta_c$ or (V_{ay}), respectively, where θ_c is the heading of the aircraft. Since both components are treated similarly, only the E-W component will be discussed here. The side of the servo amplifier (25) connected directly to the sinepot will be considered as a reference voltage level. Continuing from this point through the sinepot (23), the generator (27), the switch (26), and the second generator (28) to the opposite side of the servo amplifier (25), it is found that if both generators are stationary and the switch (26) is in the "reset" position, R, the voltage across the servo amplifier (25) is $V_a \sin \theta_c$. However, since a servo amplifier is a device which

will act to reduce any voltage across its terminals to zero, it starts the motor (29) by means of control (30). The motor speed will be of such a magnitude and direction that the generator (28) will produce a d-c voltage equal in magnitude to $V_a \sin \theta_c$ and opposite in polarity to the voltage from the sine potentiometer. The servo amplifier (25) then will have virtually zero voltage across it and if generator (28) has linear relationship between voltage output and shaft revolutions per minute the shaft (31) will be revolving at a rate proportional to the E-W component of airspeed. If this shaft (31) is connected by means of clutch (32) to the fix dial shaft (33), the crosshairs can be caused to move in an E-W direction at a rate proportional to the E-W component of *airspeed*. Likewise, the N-S velocity component can be connected to the N-S fix shaft and the radar index caused to move in a direction opposite to the air motion of the aircraft.

The motion which has been imparted to the radar index so far is proportional to *airspeed*. In order that this movement be proportional to *groundspeed* the voltage equivalent of *wind* must be added to each of the *airspeed* component voltages. This can be done by moving potentiometer arm (34) so that the servo amplifier (25) is biased in a manner causing the generator (28) output to be equal to the sum of V_{ax} and W_x. Conceivably, this adjustment could be made by a trial and error process of changing the potentiometer arm (34) position until the radar index would remain in coincidence with any radar reference on the PPI. However, since this would be a tedious process, the memory point tracking procedure was devised.

When the knob (35) is turned generator (27) produces a voltage which is added in series with the voltage V_{ax}. The result is an increase or decrease in the speed of the motor (29) for the length of time that generator (27) is in motion. This in turn causes the radar index to increase or decrease speed temporarily or effectively results in a small position change of the index. Since d-c voltage is proportional to velocity in this circuit, the product of d-c voltage and the time it is acting will give a displacement distance. This control is used as a vernier for displacement of the crosshairs, the fix knob (4) being a coarse adjustment. Now, to determine wind, the radar index must first be placed in coincidence with a fixed signal appearing on the PPI scope. This adjustment may be made with either or both of knobs (4) and (35). Secondly, the switch (26) is thrown from "reset" to "track" position (T); this also closes clutches (36), (37) and (38) and starts the constant speed motor (39). Assuming that the effect of the d-c windpot (40) was that of zero wind, the crosshairs would drift off from the radar signal at a rate proportional to the X component of true wind. The constant speed motor (39) moves the potentiometer arm (41) at constant speed across potentiometer (42). Because of this constant speed the

position of the arm (41) can be considered a measure of the time t after the motor started.

It now can be shown that, if the crosshairs are reset on the fixed radar reference at the end of time t_1 by means of knob (35), the shaft (43) will have been turned an amount proportional to the X component of wind. This follows from the fact that the displacement error, which results after a time t_1 from an incorrect rate setting, will be proportional to t_1. Since the fraction of the generator voltage which is obtained by the moving potentiometer arm (41) will be proportional to the time t, we have a means whereby the correct relationship between the displacement and the rate correction can be determined as a function of the total shaft rotation of the generator (27). A more detailed discussion of this relationship, entitled "memory point tracking," is given in the following paragraph.

Memory Point Tracking

In the memory-point-tracking operation, the rotation of knob (35) controls, as stated, the shaft (43) and the setting of the arm (34) of the d-c wind potentiometer. If the instantaneous position of this shaft is designated W_x, its rotation will then result in an output $C\frac{dw_x}{dt}$ from the generator (27) and $C\frac{dw_x}{dt}\cdot\frac{t}{T_t}$ at the potentiometer arm (41) controlled by the constant speed motor (39). Here C is a constant, t the time elapsed since the clutching in of the constant speed motor (39) at the beginning of the memory-point-tracking procedure, and T_t the total time necessary for the arm (41) to traverse the entire range on potentiometer (42). In the servo loop such an output represents a rate, similar to V_{ax}.

The drift of the crosshairs from the target since the start of the procedure results in a displacement (in the X-coordinate) of

$$\int_0^t \left(W_x - w_x - C\frac{dw_x}{dt}\cdot\frac{t}{T_t}\right)dt,$$

in which W_x is the true component of wind as distinguished from the instantaneous setting w_x, and the last term of the integral represents, of course, the effect of the generator output as modified by the setting of the potentiometer (42). If, now, the crosshairs are made to become again coincident with the target at a time $t_1 \leqq T_t$, the value of this integral becomes zero for $t = t_1$.

After integration of the last term by parts there accordingly results:

$$\left[\int_0^{t_1}\left(W_x - w_x + \frac{Cw_x}{T_t}\right)dt\right] - Cw_x\cdot\frac{t}{T_t}\Bigg|_0^{t_1} = 0.$$

If C is made equal to T_t, this becomes

$$W_x \cdot t_1 = [w_x]_{t_1} \cdot t_1.$$

Thus, the value of w_x which results is the true wind component W_x, and the crosshairs should thereafter track the target automatically.

Since the shaft (43) rotation is proportional to wind it is only necessary to connect it to the arm (34) of the d-c wind potentiometer, which, if properly calibrated, will cause the motor (29) to run at the E-W component of groundspeed. A calibrated dial (59) can be connected to this shaft to indicate wind velocity.

Since the clutch (37) is only connected during the time a wind determination is being made, the value for wind remains constant once it is determined, and knob (35) can again be used for vernier displacement adjustments. The spring return (44) is used to return arm (41) when the switch (26) is reset (R) in order that a new wind may be determined when desirable.

A "Present Position Dial" (45) is connected to shaft (31) through a slip clutch (46). This dial can be set to read zero for any position by means of knob (47) and then will continuously indicate miles distance to that point, since it is connected to a shaft rotating at a speed proportional to groundspeed.

Course Computation

By means of a switch and some of the components already described for the determination of fix, it is relatively simple to determine the heading the aircraft should have, in order that its true ground course will pass over the ground point designated on the radar scope by the crosshairs. The geometry to be solved is shown in Fig. 3. The switches marked N-C will be in the C (course) position for this portion of the discussion.

Since this computer is of the type which solves geometric problems by means of a servo loop, it is simplest to make an assumption regarding some point in the loop and later prove that this assumption is correct. Referring to part c of Fig. 4 it is assumed that the a-c voltage input T to transformer (48) is proportional to the time required for the aircraft to proceed from point O to point P in Fig. 3. The point P is the one designated by the crosshairs. The time T is obtained through the use of the circuit loop containing the transformer (48) and the airspeed division circuit (52). The output of the transformer (48) is a voltage of magnitude e_0, which will be found to be identifiable with the time-to-go T. This voltage excites the potentiometer (49) and (in the E-W channel) results in a voltage at the arm (50) which is a constant k times $e_0 W_x$. Since the switch (6) is now in the course position (C), this voltage is subtracted from that obtained from the potentiometer (1), which gave

us a measure of the distance X. Accordingly, in this channel, the input to the Arma resolver is $X - ke_0W_x$. By combining this input with the analogous input for the N-S channels, the output of the resolver will then represent $|\vec{X} + \vec{Y} - ke_0(\vec{W}_x + \vec{W}_y)|$, or $|\vec{V}_gT - ke_0\vec{W}|$. By the action of the switch (12), which is also in position (C), this quantity is applied as the input to the airspeed division circuit (52). Since the function of this circuit is to divide by the airspeed V_a, and because its output is by definition the source of the transformer voltage e_0, we are led to the following relation for the circuit loop under consideration:

$$\frac{|\vec{V}_gT - ke_0\vec{W}|}{|\vec{V}_a|} = ke_0 \qquad \text{or,} \qquad \left|\frac{T}{ke_0}\cdot\vec{V}_g - \vec{W}\right| = |V_a|.$$

The inputs $\vec{V}_a$, $\vec{V}_g$ and $\vec{W}$ are, however, connected by the vector relation $\vec{V}_g - \vec{W} = \vec{V}_a$. Accordingly, we are led to identify ke_0 with T.[5] In the following paragraph it will be seen how the division by airspeed is achieved, but, granting that this has been done, we see that the output of the unit (52) is a voltage which will serve as a measure of the time-to-go T.

In the airspeed division circuit (52)

$$e_0 = e_1\frac{R_0}{R_0 + r},$$

where $r = K(V_a - V_{ao})$, e_0 is the output voltage, and e_1 is the input voltage. V_{ao} is a constant which will be referred to as the lower limit of airspeed, and changes in the magnitude of r are proportional to changes in V_a. Since $r = K(V_a - V_{ao})$ the above equation may be rewritten

$$e_0 = e_1\frac{R_0}{R_0 + KV_a - KV_{ao}}.$$

If R_0 is adjusted to equal the constant lower limit of airspeed, KV_{ao}, then

$$e_0 = e_1\frac{KV_{ao}}{KV_a} = e_1\frac{V_{ao}}{V_a},$$

and the desired variation with V_a is obtained. Suppose next the input voltage e_1 is adjusted by moving the potentiometer arm (53) until

$$ke_1 = \frac{1}{V_{ao}}\cdot R_L = \frac{V_aT}{V_{ao}},$$

[5] For reasonable values of $\vec{V}_a$ and $\vec{W}$ $\left(\text{namely those for which } 2\frac{W}{V_g}\cos(\vec{W}, \vec{V}_g) < 1\right)$ there is only one positive value of e_0 ($ke_0 = T$), which will satisfy the equation

$$|\vec{V}_a| = \left|\frac{T}{ke_0}\cdot\vec{V}_g - \vec{W}\right|$$

subject to the condition $\vec{V}_g - \vec{W} = \vec{V}_a$.

then

$$ke_0 = \frac{V_a T}{V_{ao}} \cdot \frac{V_{ao}}{V_a} = T.$$

This represents a voltage which through the use of the desired proportionally constant k, serves as a measure of the time-to-go T. The voltage e_0 which is proportional to time T can be introduced to the time-to-go circuit (54) and thence to the time-to-go meter (55), where the amount of time before the aircraft arrived at the point indicated by the crosshairs will be shown. Likewise since the shaft position of the Arma resolver (8) now represents the direction of the vector OM (Fig. 3), an indication of the desired heading can be presented. This is done by comparing the information of the compass selsyn and the resolver selsyn when switch (56) is in the course (C) position. The difference between these selsyn outputs is introduced to the phase detector (57), and thence to the PDI meter (58) which gives the direction the aircraft should turn to be on the proper heading. Figure 3 shows that this heading will be up-wind from the desired ground track by an angle equal to the drift angle (δ). Once the correct wind information has been found by the GPI, the computer will solve the course geometry automatically for all directions of approach to the point P, and indicate the most direct route to reach that point.

PART III.

REQUIREMENTS WHICH THE USE OF GPI PLACES ON ASSOCIATED EQUIPMENT.

The accuracy of any navigational computer is dependent upon the accuracy of the data which it receives; this is true both for mechanical and human computers. However, since a machine can keep a continuous navigational log more accurately than is humanly possible, it is reasonable to expect that data sources sufficiently accurate for the human might not be so for the machine. On the other hand, there exists an economic limit to the price one will pay for navigational accuracy. In some instances extremely accurate navigation is essential and, therefore, a machine is necessary. If a machine is necessary, of course, very accurate data are required from equipment associated with the computer. From this extreme on down, various navigational needs demand varying accuracies from the navigational equipment. Because of this it is almost necessary to treat each navigational problem individually. Therefore, the following discussion will consider the accuracy of equipment associated with GPI in light of its effect on the GPI, leaving the limits of accuracy desired entirely to the reader.

Compass Requirements

By far the largest single factor affecting the performance of GPI is the compass accuracy. Since the GPI integrates the aircraft's velocity

continuously along components of the aircraft's heading, the velocity must be resolved correctly regardless of maneuvers of the aircraft. Likewise, the fix and steering data are resolved into components dependent upon the compass; therefore their accuracy also is a direct function of the compass accuracy.

It is possible for GPI results to be affected by any of three different types of compass errors. The first of these is a random fluctuation about the indicated heading, and occurs regardless of the aircraft's maneuvers. The second type of error is constant for a particular heading. Usually this results from errors in alignment, calibration, or deviation. Transient errors or temporary errors introduced by maneuvers of the aircraft are the third source.

Random errors affect the ability of GPI to navigate mainly by virtue of those vector rate errors which they introduce when a wind determination is made. In this case the only part of the random error that matters is the change in error between the time of the first fix and the time of the second fix. The significance of these errors is illustrated by the

TABLE 1.

GPI Rate Errors Caused by Random Compass Errors.

Change in Compass Error Between Fixes	Time Between Fixes (minutes)	Fix Distance (miles)	GPI Rate Error (mph)
0.5°	1.0	10	5.2
1.0°	1.0	10	10.4
0.5°	2.0	10	2.6
1.0°	2.0	10	5.2

figures shown in Table 1. In addition, random compass error at the time of the second fix will introduce a small fix error; but this is insignificant compared to the rate error.

Constant errors affect the GPI in three ways; first, by presenting an erroneous indication of distance traveled; second, by causing an erroneous fix to be taken; and third, by causing erroneous rates as a result of the fix errors introduced. The first of these is the direct result of rates being resolved into components about the wrong heading. This results in an accumulative position error. Figures for this are shown in Table 2. Fix error is caused by improper resolving of the fix components, the significance of which is shown in Table 3.

Even though the compass error may be constant it is possible that its existence will introduce a vector rate error. The reason for this lies in the fact that the rates are resolved about an erroneous heading, thus, their direction is wrong. This will not disturb the GPI operation unless an attempt is made to refer to the earth. Then, for instance, the wind vector would be off in direction. The mechanism by which the error is introduced into the GPI is by means of fixes taken at two different

Table 2.

GPI Error in Indication of Distance Traveled Caused by Constant Compass Errors.

Compass Error	GPI Error (per cent of distance traveled)
1°	1.74%
2°	3.49%
5°	8.72%

Table 3.

GPI Fix Error Due to Constant Compass Error.

Compass Error	GPI Error (per cent of fix distance)
1°	1.74%
2°	3.49%
5°	8.72%

ranges from the radar reference. With a constant compass error this results in two different fix errors. Since rate errors are a function of the difference in fix errors a rate error will result from this constant compass error. This is illustrated in Table 4.

Table 4.

GPI Rate Error Due to Constant Compass Error.

Compass Error	Distance of Fix One (miles)	Distance of Fix Two (miles)	Time Between Fixes (minutes)	GPI Rate Error (mph)
1°	10	7	1	3
1°	10	4	2	3
2°	10	7	1	6
2°	10	4	2	6

The effects of transient compass errors can manifest themselves in the GPI in three different ways. The first of these errors is in the indication by the GPI of distance traveled. Each time that a transient error occurs the rates will be resolved about the wrong heading and position error will accumulate. The amount of GPI error will depend

Table 5.

Position Error Accumulated per Turn Due to Transient Compass Errors.

Compass Error (averaged over the time that the error persists)	Time that the Error Persists (minutes)	Turning Time (for approx. this error) (minutes)	Aircraft Velocity (mph)	Position Error (accumulated for each turn made) (miles)
1°	1	½	180	0.05
1°	2	1	180	0.10
1°	1	½	240	0.07
1°	2	1	240	0.14
5°	1	½	180	0.25
5°	2	1	180	0.50
5°	1	½	240	0.35
5°	2	1	240	0.70

entirely upon the magnitude of the transient and the time for which it persists as well as the velocity of the aircraft. Transient errors usually arise as a result of turns made by the aircraft. Figures illustrating these errors are shown in Table 5.

The second effect of the transient compass error is to cause fix errors. The fix error is entirely dependent upon the magnitude of the compass error and is the same as shown in Table 3.

The third effect of transient errors is to cause rate errors the same as those caused by random errors (Table 1). In this case, however, the rate errors brought about by erroneous fixes would be larger, because changes in transient errors are of greater magnitude than those of the random errors. Further illustrations of these errors are given in Table 6.

TABLE 6.

GPI Rate Errors Caused by Transient Compass Errors.

Change in Compass Error Between Fixes	Time Between Fixes (minutes)	Fix Distance (miles)	GPI Rate Error (mph)
1°	1.0	10	10
5°	1.0	10	52
10°	1.0	10	104
1°	2.0	10	5
5°	2.0	10	26
10°	2.0	10	52

In summary, it can be stated that fix and integration errors are the two major errors introduced directly by the compass. Rate errors in wind determination are brought in by a change in fix error regardless of the source of error. One source is the compass.

At this writing there exist several compasses with varying degrees of accuracy. However, these all have faults which make them undesirable as they are now constructed. Of the several compasses suitable for aircraft use, the "Gyrosyn" built by Sperry Gyroscope Company is the most satisfactory since its basic design permits simple modifications which greatly increase its accuracy.

Airspeed Meter Requirements

The use of GPI requires that there be available a true [6] airspeed meter from which in some manner a voltage can be derived. This voltage must be proportional to the true airspeed of the aircraft. A number of commercial meters exist, at this writing, which with or without slight modifications fulfill the voltage requirement.

[6] "True airspeed" as distinguished from the commonly used "indicated airspeed" is a measure of the true velocity of the aircraft relative to the air mass in which it flies. Indicated airspeed is simply an indication of the relative pressure exerted by the air mass in the direction opposite to the motion of the aircraft, and as such, depends upon the density of the air.

The accuracy requirement placed upon the airspeed meter is again a matter of judgment which depends on the navigational needs. Of course, if it is permissible to "determine wind" each time the airspeed or heading changes almost any meter will do since fictitious winds computed will compensate for the airspeed errors. However, if freedom of operation is desired and a correct value for wind is wanted, the airspeed requirements are more stringent.

Airspeed errors, as with the compass, are of three types—random, transient and constant. The random errors do not affect the GPI operation unless the magnitude of variation is extreme. Since most meters are satisfactory in this respect, random errors will not be discussed further except to say that they cause position errors from moment to moment which are averaged out in the total mileage indication. Transient airspeed errors usually occur in the form of a lag in response to changes of aircraft speed or altitude. This lag can cause either an integration error, or, if it occurs during a wind determination, a rate error. Since in most present day airspeed meters, the lag is of small magnitude and time duration, and also since it is common for aircraft to fly for long periods at a relatively constant speed, the integration errors from this source are negligible. Likewise, a GPI operator, if necessary, can avoid any error from this source in wind determination by determining wind only when there are no radical changes in airspeed being made.

About the only appreciable errors from present day airspeed meters are the constant errors. These are usually caused by faulty calibration, or improper installation. The effect of a constant airspeed error is to cause the GPI to compute a wind error of equal magnitude and opposite sense. An error of this type will not cause any error in the indication of distance traveled as long as the heading on which the wind was determined is maintained. However, if a change in course is made, both an incorrect heading and rate will be indicated. The net result due to both the heading and the rate errors will be that the position indicated on the GPI dials will be in error by an amount which can be expressed

$$\epsilon = .033 \cdot \delta V_a \cdot t_e \sin \frac{\Delta}{2},$$

where

ϵ = Position error in miles,
δV_a = Constant airspeed error in mph,
Δ = Angular measurement of change in heading in degrees,
t_e = time in minutes elapsed since turn was made.

Table 7 gives some typical values for errors that might be expected from this source.

In general, the true airspeed information available for GPI operation is good compared to other data such as the compass data. However,

TABLE 7.

GPI Position Error in Miles Due to Constant Airspeed Error at a Time Ten Minutes After Making a Given Turn.

Change of Heading	True Airspeed Error		
	1 mph	5 mph	10 mph
0°	0.00 miles	0.00 miles	0.00 miles
5°	0.01 miles	0.07 miles	0.14 miles
10°	0.03 miles	0.14 miles	0.29 miles
20°	0.06 miles	0.29 miles	0.57 miles
30°	0.08 miles	0.43 miles	0.85 miles
90°	0.23 miles	1.17 miles	2.34 miles
180°	0.33 miles	1.65 miles	3.30 miles

GPI Position Error in Miles Due to Constant Airspeed Error at a Time 30 Minutes After Making a Given Turn.

Change of Heading	True Airspeed Error		
	1 mph	5 mph	10 mph
0°	0.00 miles	0.00 miles	0.00 miles
5°	0.04 miles	0.22 miles	0.43 miles
10°	0.09 miles	0.43 miles	0.86 miles
20°	0.17 miles	0.86 miles	1.72 miles
30°	0.25 miles	1.28 miles	2.55 miles
90°	0.70 miles	3.50 miles	7.00 miles
180°	0.99 miles	4.95 miles	9.90 miles

some care should be taken when an airspeed meter is installed, for even the best of meters perform badly unless they receive proper pressure and temperature data. It will be found that if considerable care is taken during installation and calibration, the airspeed errors in GPI will be negligible.

Radar Requirements

The GPI requires that the radar system with which it is used provide a synchronizing trigger and spinner (antenna) azimuth data. The trigger is usually derived from the radar output pulse. The azimuth information is received from a selsyn unit rotated by the radar antenna assembly. In turn, the GPI provides an azimuth mark and a range mark as an index on the radar PPI.

The previous discussion has shown to what extent GPI depends upon fix information. The computation of fix determines present position relative to a known land mark and indirectly determines the ground velocity relative to that reference. Because of these two facts, anything which contributes to the accuracy of fix determination is important to the GPI performance.

The resolving power of a radar system is the factor which determines how accurate a fix can be taken with it. Further, this resolution de-

pends upon the transmitted frequency, pulse length, beamwidth, spot size of the PPI, PPI sweep speed (radial scale factor), and persistence of the tube. So far as this discussion is concerned, present day radar systems operate at high enough frequency and have short enough pulses to make extremely good navigational devices. On the other hand, the sweep speed, spot size, beamwidth and tube persistence, which contribute to GPI fix accuracy, leave something to be desired.

Since the accuracy of GPI fix is dependent upon how well a reference signal is seen and upon the accuracy with which an index can be placed coincident with that signal, it is logical to consider this process. It is assumed for the present that the method of adjusting crosshairs to the radar reference is to make the azimuth mark bisect the reference and the trailing edge of the range mark just tangent with the leading edge of the reference. Accuracy of the range adjustment is largely dependent upon the spot size and sweep speed of the PPI tube. The accuracy of azimuth adjustment depends upon the beamwidth, range, and size of the target. Both of these factors are affected by the persistence

Table 8.

Sweep Speed	Range Accuracy
8 miles/inch	0.16 mile
6 miles/inch	0.12 mile
4 miles/inch	0.08 mile
2 miles/inch	0.04 mile
1 mile/inch	0.02 mile

of the radar scope if the aircraft is traveling at high speed or is rolling and pitching.

The sweep speed which should be used on the radar set for GPI depends once more on the needed navigational accuracy. If the trailing edge of a range mark is considered to drop off instantaneously, then the apparent point at which it drops off as it appears on the PPI will be one-half of the spot size of the tube beyond the true point. Likewise, if a signal rises instantaneously it will appear to start one-half spot size ahead of its true position. Thus, if the trailing edge of a range mark and the leading edge of a signal were made tangential as they appear on a PPI there would exist an actual gap of one spot size between the true edges. Since the spot size of a tube is constant regardless of sweep speed for sweeps commonly used with GPI, the distance in miles per spot size will change with sweep speed. If a signal does not rise instantaneously the previous statements are still true and in addition, the true leading edge and trailing edge will also change as a function of radar receiver gain and PPI brilliance adjustment. Assuming a spot size of 0.5 millimeter, Table 8 has been prepared to show the order of magnitude of the range accuracy in miles which might be achieved if it is assumed the gap between range mark and signal is one spot size.

A radar range measuring system can only be calibrated conveniently for one particular sweep speed since the spot size will cause a signal to appear at different apparent ranges on different sweeps. Since this is a fix error, there will also be the rate errors which are associated with changes in fix errors. For instance, it can be seen that an erroneous rate of 2.4 mph would be determined if the sweep speed were changed from 4 miles/in. to 2 miles/in. during the process of measuring a GPI wind, and if the time between fixes were one minute. This would be caused by the difference in apparent range between fix one and fix two of the wind measurement. For these reasons, it is recommended that one standard sweep speed be used when making range measurements. It is apparent that if the sweep speed is to remain constant the maximum range at which a fix can be taken will be given as the product of the sweep speed in miles per inch and the radius of PPI scope in inches unless special provision is made. It is suggested that the most desirable method for avoiding the range limitation is to use a delayed sweep, preferably of the offset-center type. This allows a fast sweep with low distortion to be used at ranges much greater than otherwise.

Experimental tests performed by the authors have shown that a range mark can be adjusted repeatedly to the same point on the face of the PPI tube within ± 0.01 inches using the equipment discussed in this article. This figure has been called setability or resetability by various authors. It should be remembered that this figure for setability is necessarily true only for the method employing tangential comparison of two marks.

The technique of bisecting a radar reference with an electronic azimuth mark is somewhat more complex in analysis than that of the range mark. The true size of a radar reference is the same for one range as another. Therefore, it would be expected that at great range the angle subtended by the reference would be small and the angular accuracy with which that angle may be bisected is high compared with that of larger angles. On the other hand, if the radar beamwidth were assumed to subtend a constant angle, the width of a radar signal would be a function of the range multiplied by the sine of the angular beamwidth. This means that the farther the reference, the broader it would appear on the PPI; therefore, the accuracy of bisecting would be low. Actually, what appears on the PPI scope, is a signal whose width is reference width plus the apparent radar beamwidth at the range in question. Since present antenna patterns do not achieve the ideal of constant illumination regardless of range, the radar angular beamwidth appears to be narrower at great ranges than at short ranges. So, a signal in general does not appear to increase greatly in width at great ranges. Therefore, as the reference approaches, the beamwidth increases, and the signal width is increased. This assumes that the reference echo itself remains constant in width. However, since the reflecting surfaces of various

landmarks are different, their apparent widths may be wide or narrow or may even change as a function of range. Since the results are very much dependent upon the nature of the reference it is necessary that care be exercised in selecting radar landmarks to be used for GPI fixes. If point references are used, the azimuth resolution of the system is the determining factor for setability. The results of experimental work by the authors indicate that setability is approximately $\pm 0.6^\circ$ on point references. This would indicate that with an excellent target located at ten miles the azimuth fix error in nautical miles would be ± 0.1 mile. Further, it is not unreasonable to expect wind determination errors on the order of six to ten miles per hour from this source.

In addition to the range and azimuth errors just discussed, errors which will either add to or subtract from these may be caused by the use of long persistent PPI tubes. For example, if the GPI aircraft is traveling at a ground rate of 200 mph the edge of a signal will move a distance on the PPI corresponding to 0.16 mile during the period of one revolution of a "standard radar spinner." If the persistence of the tube is such as to preserve one picture until the next is painted, then the targets will have indistinct edges of approximately 0.1 mile in the direction of aircraft travel. Since all fix comparisons are made at the time when the signal in question is being painted on the radar scope, this particular effect of persistence only causes errors through operator confusion. However, the process could be made easier with rapid scan, low persistence radar systems.

One effect of roll and pitch of an aircraft is to cause a blurred picture due to motion of the signal on the PPI. However, the simple remedy of placing the crosshairs at the time the signal is painted on the PPI is not effective in this case. This is because roll and pitch actually make the reference appear at a wrong azimuth position and therefore give rise to fix error. The only true solution to this problem (if it is to be used in aircraft where roll and pitch are prevalent) is to stabilize either the radar antenna or the GPI crosshairs to compensate for motion of the aircraft.

Summary of Requirements

It is felt that the GPI computers which have been designed for aircraft are capable of navigating with precision equal to and with facility exceeding that of ordinary navigational aids used in the past. However, the reliability of any information supplied by the navigator or by a machine such as GPI can never exceed the reliability of data used in calculating this information. Until recently, conventional airspeed meters, compasses, drift sights and other devices for collecting data have been of sufficient accuracy to satisfy the navigational requirements. With the coming of high speed aircraft, however, errors in navigation formerly considered negligible will presently result in failure of the air-

craft to maintain its place in the traffic pattern, wasted air mileage (with attendant lowered efficiency), and increased cost of operation.

GPI offers a convenient means for navigating, since it supplies complete navigational information continuously and automatically and requires a minimum of attendance during flight. But the GPI can only perform as accurately as the associated components on which it depends. The present accuracy of the GPI is such that further improvements in computer accuracy will not result in better system performance without improved results from the associated equipment. In particular, the GPI has taken over all functions of navigation to the point where major sources of error may be traced to the compass.

PART IV.

TECHNIQUES OF USING GPI.

The basic philosophy of GPI is applicable to other types of vehicles as well as aircraft. Indeed, the device that has been described in the preceding sections, although originally designed for aircraft, could very easily be modified for use on board ships, tanks, or other vehicles. In fact, the procedures which have evolved from the use of the GPI equipment described herein might well be useful to the art of navigation, regardless of the vehicle. Of these, perhaps the use of GPI to assist in the identification of towns, cities, or other landmarks is most interesting. The principles of identification employed by GPI are not unique, but the GPI technique facilitates recognition of landmarks through use of navigational data. This technique, as well as other useful procedures, is given in this article in order to illustrate some of the uses to which GPI can be put. The procedures given have all been used in flight and have been shown to be extremely satisfactory.

Navigational Procedure

The practice of GPI navigation has been made simple and permits accurate navigation with great facility. This procedure is outlined in four steps as follows:

1. Determine radar altitude.
2. Measure wind.
3. Set present position dials to indicate position of aircraft.
4. Proceed with "check point" navigation.

The radar altitude is found with the GPI by pushing in on the altitude knob and turning until the range mark is coincident with the first ground signal on the PPI scope.

Wind is measured and entered into the computer by first setting the GPI crosshairs to any prominent radar signal on the PPI scope.[7] A

[7] The signal should be one which will not change in appearance during the next one to three minutes.

switch button is pressed, and after a short waiting period, during which the crosshairs may drift away from the radar signal, they are reset to it. Thereafter, so long as the wind does not change, the crosshairs should remain in coincidence with any radar reference signal on which they are set.[8]

The fix dials indicate in N-S and E-W components the ground range and direction to any reference on which the crosshairs are set.

In Fig. 5 the fix dials (outer dials) show that the crosshairs are set on a point which is 18 miles north and 11 miles east of the aircraft. If the aircraft should proceed to this point the zeros of the fix dials will then have moved under the cursor, and on the PPI the crosshairs will have moved into the center of the oscilloscope. Clearly, the zeros of the fix dials may be thought of as representing the crosshairs. Suppose the crosshairs to be set on a reference whose mileage coordinates are known with respect to home base. If the present position dials then are turned until these mileage coordinates lie opposite the fix dial zeros (crosshairs), the present position of the aircraft with respect to home base will be indicated on the present position dials under the cursor.

In the example of Fig. 5, the crosshairs have been set on the PPI to a point which is known to be 118 miles north and 61 miles east of home base. The fix dials indicate that this point is 18 miles north and 11 miles east of the aircraft. This means that the aircraft is $118 - 18 = 100$ miles north and $61 - 11 = 50$ miles east of home base. In Fig. 5, the present position dials have been set so that the coordinates of the known point (118N and 61E) lie opposite the zeros of the fix dials. The present position of the aircraft is now indicated under the cursor on present position dials. This constitutes step three of the navigational procedure.

The "check point" system of navigation is employed to indicate by means of the PDI meter (Pilot's Direction Indicator) the heading the aircraft must follow in order to pursue a given ground track. The mileage coordinates with respect to home base of any convenient point which lies on the desired ground track are selected by reference to an aeronautical chart or other source. This point is one over which the aircraft should pass in order to be on course (see Fig. 5), and it need not produce any radar signal. The fix dials are then turned until their zeros come opposite the mileage coordinates of the point in question. This operation places the crosshairs over this point on the PPI scope even though there may be no radar signal. If now the function switch is turned to the course position (*C*), the PDI meter will indicate a heading for the aircraft to fly which is upwind from the desired ground track by an amount equal to the drift angle. And the TTG meter (time-to-go) will indicate the time in minutes before arrival at the

[8] Of the four steps mentioned above in the navigational procedure the processes of the first two have been discussed in Part II of this article.

selected point. This procedure of setting up check points for the GPI may be repeated as many times as desired until the aircraft arrives at its destination. If the aircraft has wandered off course during a time when the GPI may have been left unattended, the setting up of a single

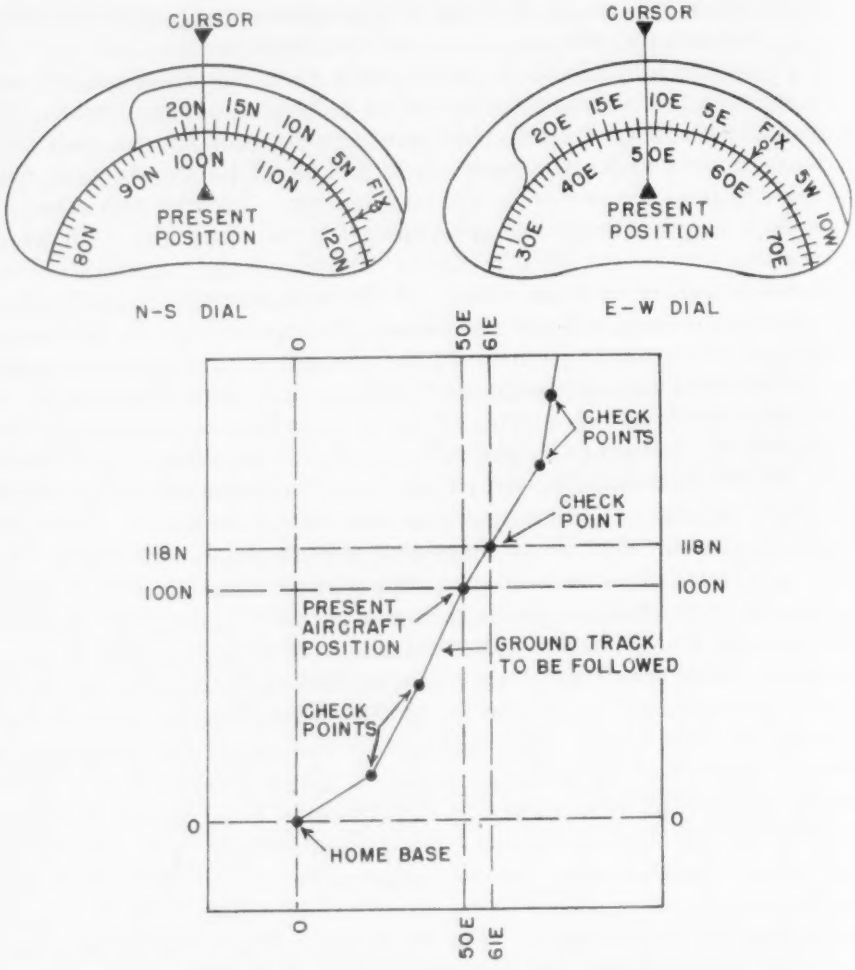


FIGURE 5.
PROCEDURE FOR CHECK POINT NAVIGATION.

check point will bring it back to the prescribed ground track, and a second check point will cause the aircraft to be turned on course. If the check point system is used, and if a new wind is found every time there is reason to believe it has changed, a predetermined course can be flown very accurately.

Identification of Radar Signals

Radar signals appearing on a PPI tube can be identified by use of the GPI. One procedure for this would be to place the crosshairs on the unknown signal and then to read the mileage coordinates of that signal from the present position dials opposite the zeros of the fix dials. By reference to a navigation chart showing these coordinates the geographic location of the unknown signal can be found. Conversely, if it is desired to select one desired signal appearing among a number of other signals on the PPI, it is only necessary to set the fix dial zeros opposite the mileage coordinates of the desired signal on the present position dials. Then the crosshairs will appear over the desired signal on the PPI.

Classification of Reference Points for GPI

The GPI technique divides reference points into three categories:

1. *Principal references* are those which by nature of their shape or position relative to other signals may be easily and positively identified by the use of radar with ordinary charts. GPI use is not essential for these references. Principal references are used to set the present position dials at the beginning of the navigational procedure. Since GPI is subject to a certain accumulative position error, the present position dials may have to be reset occasionally. This may be done only when the reference can be positively identified by radar alone. The importance of using only principal references to set the present position dials is stressed. The philosophy behind this is that in the absence of positive identification, the best information available is that stored in the GPI.

2. *Intermediate references* are those which appear as good radar signals but are not easily identified without a complete knowledge of present position. GPI use is essential for these references.

3. *Local references* are those which appear as small, weak radar signals. There are usually many of these unidentified signals appearing on the PPI. One of these can be picked up and identified by manipulating the fix dials to known coordinates of the reference and allowing the crosshairs to identify it on the radar scope. The aircraft's destination may well possess such characteristics. If the crosshairs are set to the destination signal on the radar, the GPI will compute a very accurate estimate of arrival time.

In general, it should be stated that only some known discreet point of a reference should be used for fix or wind determination. The only purpose that the remaining larger portion of the reference point serves is to aid identification.

Future GPI Techniques

The description and procedures of the preceding sections are concerned with a specific version of GPI. This GPI uses a rectangular coordinate system of computing and presenting data. Furthermore, this GPI requires an operator to judge when changes in wind make necessary a new computation of wind. At this writing there exist in the design stage several new types of GPI which treat these problems differently.

A unit designed by the Radiation Laboratory is expected, as a result of new construction techniques, to weigh only thirty-five pounds in addition to the radar system. This design permits present position to be shown in latitude and longitude. Identification can also be made in latitude and longitude while the presentation of fix is given as miles from aircraft to reference. The major change that is made for a lat.-long. presentation is multiplication of the E-W rates by the secant of degrees latitude representing the N-S position. This design also provides a system of counters and differentials in place of dials. With a system of this type there would be three sets of counters, one giving fix presentation, a second giving present position of the aircraft, and the third giving the position of the crosshairs relative to home base. The third set could be labeled identification. The counters would then be used in the same way as the dials, but their presentation would be clearer.

Other refinements of the GPI philosophy will almost surely include continuously automatic altitude measurement. At this writing, operatorless GPI's are being designed which solve continuously all problems of navigation including the determination of drift angle. This type of GPI does not require a search radar but rather uses sonic or radar doppler principles, or beacons to obtain continuous data relative to ground speed and drift.

The authors are greatly indebted to Dr. L. J. Laslett for his editorial comment and assistance.

The initial phases of the development of this navigational technique are largely due to the efforts of B. Chance, I. A. Greenwood, J. W. Gray, D. MacRae, R. Kelner, W. Proctor and A. C. Hughes. As the development grew the efforts of many others were required including R. K. Mosher, A. S. Bishop, H. J. Reed, G. W. Rodeback, S. A. Martin, A. H. Fredrick, F. B. Dibble and G. A. Jarvis.

THE PROSPECTS OF CONSERVANCY WORKS IN CHINA.

BY

BAZIN SHEN,

Chairman of The Hydraulic Engineering Society of China, 1945.

Chapter I. Historical Recapitulation 400
Chapter II. Principal Conservancy Works since the Revolution of 1911, up to the war. 401
Section I. On North China Rivers 401
(1) Flood Prevention 401
(2) Navigation 403
(3) Irrigation 404
(4) Experimentation 404
Section II. In the Yellow River Basin 404
(1) Flood Prevention 404
(2) Irrigation 405
(3) Model Test and Erosion Prevention 406
Section III. In the Huai River Basin 406
(1) Flood Control Project 406
(2) Navigation Project 406
(3) Irrigation Project 406
(4) Water Power Development 407
(5) Works already executed In the Huai River Basin 407
Section IV. In the Yangtze River Basin 409
(1) Flood Control 409
(2) Navigation 409
(3) Irrigation 409
Section V. In the Pearl River Basin 410
(1) Flood Prevention 410
(2) Navigation 410
(3) Irrigation 411
Section VI. Hydraulic Researches 411
(1) Laboratory tests 411
(2) Hydrological surveys 411
(3) Aerial surveys 412
Chapter III. Conservancy works performed during the war against Japan 412
Section I. Flood Prevention 412
Section II. Navigation 412
Section III. Irrigation 414
Section IV. Hydraulic Researches 415
Chapter IV. Post-war Conservancy Rehabilitation Plans 416
Section I. General Principle and Suggested Plan 416
(1) Aim 416
(2) Scope and Capacity 416
(3) Division of Districts and Periods 417
a. Flood Prevention 417
b. Navigation 418
c. Irrigation 418
d. Water Power 418
Section II. Preparatory steps 419

CHAPTER I. HISTORICAL RECAPITULATION.

Conservancy achievement is marvelously predominant in the ancient history of China. Dating back about 2000 B.C., there was an enormous flood, which inundated the greater part of China. And it was the most famous Emperor Yu, a sage and also a hydraulic engineering genius, who rose from a humble life, and with his remarkable ability pacified the flood and made the whole China soil suitable for cultivation, thus effecting the unification of the Empire. On the abdication of Emperor Shun, Yu took the throne in 2205 B.C., and was made the first Emperor of the Hsia Dynasty. So at that time, the primitive central government of China was founded on the basis of conservancy accomplishments.

Later in the Chou Dynasty conservancy enterprises were still greatly emphasized. As described in the classic, "Chou Rituals," a complete system for irrigation and drainage was definitely devised. Toward the decline of the Chou regime, the feudal states made constant wars on each other and became careless about river works. During the reign of Emperor Ting, about 600 B.C., the Yellow River began to make trouble. Conservancy works again drew the attention of the government in the Chin Dynasty, which began to rule the whole empire in 256 B.C.; the famous Chen-Kou Canal in Shensi province and Tu-Kiang-Yen Canal in Szechuen province were among the hydraulic accomplishments which led to great prosperity of the people. Liang Canal and Ling Canal connecting the northeast with the southeast and southwest of the country, and Ning-Hsia Canal, dug by the great general Mon-Dien, irrigating a vast area on the northwest frontier, were made in the Chin Dynasty.

The hydraulic works in the Han Dynasty achieved great improvements, and irrigation was characteristic of the age. Irrigation canals and reclamation were extensively developed in Ning-Hsia province as far west as Ching-Hain. And irrigation systems were universally adopted in China Proper. The Sui Dynasty, A.D. 589–618, was famous for the excavation of the Grand Canal, which is the oldest and longest canal ever in existence, extending from Peiping to Hangchow, covering a distance of 2074 kilometers, passing through Chekiang, Kiangsu, Shangtung and Hopei provinces. For many centuries it was the main artery of communication between the north and the south, serving as the transportation route for the government's tariff (in the form of rice and ordinary commodities).

During the East-Han Dynasty about A.D. 150, a noted scholar, named Wang-Ching, proposed to erect sluice gates, every three miles, along the river dykes for the purpose of relieving the flood water and irrigating the land. This won the admiration of the people, and Wang-Ching has been worshiped as a hydraulic genius only next to Emperor Yu. His teachings about river works were and are still considered of permanent value. In the following Dynasties, we had also many

excellent hydraulic experts, notably, Cha-Lu of the Yuan Dynasty, Pan-Ki-Ching of the Ming Dynasty, and Chin-Fu of the Ching Dynasty, who all rendered invaluable services on river work, especially on the Yellow River, and whose theories and principles for the execution of works were closely in coincidence with those of modern scientists of western countries.

In former times, hydraulic works, mostly based upon personal experience, were performed in a non-scientific manner. It was not until a few years before the founding of the Republic that Mr. Chang Kien of Nan-tung, Kiangsu, began to adopt Meteorological and Hydrometric observations to be applied on river works, thus laying the foundation for the modern hydraulic engineering in China. After the establishment of the National Government in 1927, various conservancy administrations have been organized for the principal waterways in the country, such as the Yellow River Commission, Yangtse River Commission, North-China River Commission, Huai River Commission and Pearl River Commission, to take charge of all Conservancy matters, including navigation, irrigation, flood prevention, and development of water power in their respective drainage basins. Also the Central Hydraulic Laboratory has been established for the purpose of testing and making all hydrometric appliances of more or less experimental nature. Considerable reconstruction works had been or were being made by these various organizations before the outbreak of the present Japanese aggressive war. But, of course in the occupied area they have all been devastated by the enemy.

In the following paragraphs, we shall give a brief description on some of the conservancy works already accomplished before the war by the aforementioned offices, for the sake of reference, and shall describe some recent works executed during the war, and also mention something about our post-war projects, to show that China's resistance war and its rehabilitation work were carried out on somewhat paralleled lines.

CHAPTER II. PRINCIPAL CONSERVANCY WORKS SINCE THE REVOLUTION OF 1911, UP TO THE WAR.

Section I. On North China Rivers.

(1) *Flood Prevention.* By North China, we mean the vast area of about 622,000 sq. kilometers, situated north of the Yellow River, with mountainous terrains in the western part and an alluvial plain in the eastern part, drained by many turbulent waterways, of which the Yung-Ting River is the most trouble-making one, being heavily laden with silt. Owing to its nearness to Peiping, the capital of China for many dynasties, the Yung-Ting River's condition always drew the first attention of the government. The river bottom was continually raised by silt deposit, resulting in overflow and inundation, and the only way for the officers in charge to tackle the problem was to build the levees

up higher. But any breach in the dykes still caused disasters. The floods of 1917, 1924 and 1929 were all big calamities in North China. Therefore the conservancy problem for that area is chiefly one of flood prevention, for which the following works were purposely made.

a. The Southern Dyke Around Tientsin. During the flood of 1917, the Tientsin municipality was submerged for three months. In the following year a dyke was built around the southern suburbs, and prolonged in 1920, and again prolonged and strengthened in 1924, thus completing a wall for protection against floods.

b. The Regulators on the North Grand Canal. The upper northern Grand Canal breached its dyke at Li-Suig-Chen, east of Peiping in 1912. It was closed in the spring of the next year but was opened again during the Autumn flood of the same year. Later in 1923, the Chili River Commission began to excavate a new canal, 7 Km. long, and to construct 2 regulators at the site, one with 39 openings, and another with 19 openings. All these works were completed in 1925.

c. The sluice at Tu-Men-Liu. For the purpose of controlling the discharge of North Grand Canal, a sluice was constructed at Tu-Men-Liu, the junction of Grand Canal with the Ching-Lon-Wan River, in addition to an original spillway. It consisted of 40 openings, each 3 m. wide, so that the surplus water in Grand Canal could be controlled by diversion into the Ching-Lon-Wan River.

d. The New Diversion Channel at Ma-Chang. The diversion channel at Ma-Chang was originally excavated about 1880 to release the flood water in the South Grand Canal, but being without proper repairs, it had become out of order. In 1918, The Chili River Commission undertook to excavate a new diversion channel connecting with the old one to accommodate a maximum discharge of 100 cu. m. per sec., and also to construct at its inlet a sluice of 6 openings, for the perfect regulation of the flow.

e. The Shin-Kai River Sluice and its leading channel. The function of this channel was to discharge a part of the flood waters in the Yung-Ting River, the Tse-Ya River and North Grand Canal. A sluice of 14 openings, each 3 m. wide, was constructed in 1919, capable of passing 220 cu. m. per sec., with a lock provided at its side for navigation. The channel was 13 kilometers in length.

f. The Closing of Yung-Ting River Breaches. Between 1912 and 1929, the dykes of Yung-Ting River were broken six times by flood water, each causing a disaster of considerable magnitude. All the gaps were closed in due time. The closing work of 1924 was accompanied by the erection of several stone spur dikes which subsequently proved very effective, and in 1929 the Marco Polo bridge with its adjacent spillway was extensively repaired, together with other protection works.

g. The Loong-Foon River Regulator. Loong-Foon River flows into

the Grand Canal, south of Tientsin. But the flood water in the latter frequently flowed back into the former, causing inundations therein. In 1935, there was constructed at the junction of Loong-Foon River a regulator of 8 openings, each 4 m. wide, which has done away with the backwater effect.

h. Yung-Ting River Project. A complete project for the improvement of Yung-Ting River was drafted in 1931 by the North China River Commission. Its chief aim was to diminish the silt content and to minimize the flood water, taking into consideration the opinions expressed by the experts from the League of Nations. Its principal work consisted of the construction of the Kwan-Tin Reservoir. The site of dam began to be tested with borings in 1935, and would have been finished by 1940, had not the war broken out.

i. Other Projects. Other projects of importance, set forth by the North China Rivers Commission, included the Ta-Ching River Diversion Channel, Tse-Ya River Diversion Channel and Kia-Kan River Works, of which all the plans had been adopted, but not executed due to the war.

(2) *Navigation.* In the North China Plain, the Hai River connecting Tientsin Municipality to the sea, is the most important waterway so far as navigation is concerned. Other waterways such as Grand Canal, Lur River, Ta-Ching River, Tse-Ya River and Liao River are all of navigational importance.

a. Liao River. It is the chief navigational artery in the three eastern provinces. In the flood of 1908, two-thirds of its discharge were diverted away through breaches to the countryside, making the navigation situation extremely precarious. The then local government established the Liao River Engineering Bureau in 1914 to take care of it, and all sorts of improvement works including dredgings, cut-offs, trainings and regulators were made in subsequent years.

b. Hai River. The Hai River, 45 km. in length, is the main outlet of five big waterways. The first steps of improvement taken by the Hai River Works Bureau were to close side channels, erect spur dykes, and make cut-offs, supplemented with continuous dredging. Besides, the excavation of sand banks in the estuary, the ice-breaking in the winter time and the silt-depositing on the shallow land by the riverside all produced fairly good results. The Bureau was later reorganized into the North China River Commission, which functioned up to the war.

c. Grand Canal. As mentioned in the preceeding pages, the Grand Canal has been the main transportation route between the north and the south for more than one thousand years. But since the completion of Tientsin-Pukow Railway, a parallel communication line, about forty years ago, the traffic on the Canal has greatly diminished. In 1933, a Commission for the regulation of the Canal was organized by all

offices concerned, local or governmental, and formulated a project for its improvement, which was never executed.

(3) *Irrigation.* North China, being a vast agricultural plain, is of comparatively arid climate; therefore irrigation works are always deemed necessary. In the former days, those works, made by local people, did not prove very satisfactory. Later, the Agricultural and Conservancy Commission of Hopei Province, assisted by the International Famine Relief Association, exerted efforts to carry out many irrigation plans, which had good results.

a. How-Tu River Irrigation Works. This was a plan to draw water from the How-Tu River to irrigate four districts, covering an effective area of 20,000 acres, costing about $600,000. The engineering work took three years from 1933 to 1935.

b. The first irrigation plan of Sang-Kan River. The plan was to draw silted water from Sang-Kan River to irrigate and silt up the land on both sides of the river, covering an area of approximately 160,000 acres. The weir and head works had been about 90 per cent. completed at the outbreak of the war.

c. Yang River Irrigation Works. This project, like the former one, was planned to irrigate with water, but at the same time to utilize its silt content to fill up the shallow land. It was located in Charhar province, taking water from the east Yang River, and covering an area of about 33,000 acres, to the north of Peiping-Suiyuan Railway. Its dam site was tested, and decided upon in 1927, but construction work was suspended due to the war.

d. Golden Gate irrigation and silting works. The plan was to utilize the water from two openings of the Golden Gate-Sluice of the Yung-Ting River, south of Peiping, to irrigate and silt up an area of about 17,000 acres. This work was largely performed by Jan. 1937.

e. King-Chung River Reclamation Project. This project was to provide a drainage system on the low land, and to have the water collected and pumped to a new channel. When necessary, the water in the new channel was taken back for irrigation. This was completed in 1935.

(4) *Experimentation.* In 1935 the North China River Commission purchased a piece of land of 700 acres area at Ning-Ho-Hsien, Hopei, for experimentation purposes. Nine-tenths of the area was used for model irrigation, and the rest used as an experimentation field to test the rates of water consumption with various kinds of crops, through different methods of irrigation and drainage.

Section II. In the Yellow River Basin.

(1) *Flood Prevention.* Known as China's Sorrow, the Yellow River has caused so many disasters in Chinese history, that the central

government in the earlier dynasties always appointed special governors for the river, and expended enormous amounts of money for its control, but no reliable solution has so far been reached. The Yellow River Commission, inaugurated in 1933, began to devise plans for its permanent control by making detailed surveys and laboratory tests, and also repaired various parts of dykes and from time to time closed different breaches. Within the first four years of its organization, the Commission had completed the topographic and leveling surveys in the whole lower reaches of the river, together with the collection of hydrographic and meteorological data. A few of the projects and works are as follows:

a. Projects for Regulation of Channel and Storage Reservoirs. The regulation of the channel around the Peiping-Hankow Railway bridge, the regulation of the channel at Tung-Hwa-Shien, the plan for a diversion channel near Tu-Hsien River, the plans for storage reservoirs at Shen-Chow and Pao-Chi-Sha, and the plan for training walls at the estuary were all among the finished projects ready for execution.

b. Dyke Works. The dykes of the Yellow River were originally taken care of by the different provincial authorities concerned. Since the Yellow River Commission came into existence, it has exerted a unified control. Three well known breaks of dykes at Fong-Liu in 1933, at Kwan-Tai in 1934 and at Tung-Chwan in 1935, kept the Commission busy to its full capacity, and were all repaired with enormous effort. Besides, the Commission built various bank protection works, dyke strengthening works, spur dykes, closing dams on branch channels, and the regulation of some tributaries.

(2) *Irrigation.* In Shensi province, we see the most efficient and extensive systems of irrigation in the whole of China. They were sponsored and personally directed by the late Professor H. Lee, a noted hydraulic engineer and scholar. Owing to the fact that these irrigation systems all take water from the tributaries of Yellow River, we mention them under this general heading.

a. Gin-Wei Irrigation System. Drawing water from Gin River, the Gin-Wei canal approximately followed the trace of the ancient Chun-Pai canal of the Chin and Han Dynasties, and ran through five hsiens, capable of irrigating more than 100,000 acres in a complete system of sub-canals and irrigating ditches. Its construction took two years from 1931 to 1932.

b. Wei-Wei Irrigation System. The Wei River drains the vast plain of Shansi, which is fertile soil from an agricultural point of view. The Wei-Wei irrigation canal, diverted from the Wei River at Wei-Chia-Pao where a dam and head works were built, ran along the north bank to sub-canals and ditches, covering an irrigation area

of about 90,000 acres. The construction work took four years from 1935 to 1938.

c. Mei-Wei Irrigation System. This irrigation canal started from a point about 10 miles southwest of Mei hsien, where it took water from the Shih-Toa River, and covered an area of about 14,000 acres. Its construction was started in 1936 and was finished in 1938.

Besides these there are nine other completed irrigation systems, all in Shensi province.

(3) *Model Tests and Erosion Prevention.* The Yellow River Commission in 1936 secured a piece of land, about 40 acres in area, at Kai-Fang, Honan, for a large scale laboratory. It intended to make model tests for the maintenance of river channels. The Commission also established an erosion prevention laboratory at Ling-Pao, Honan, but the testing works were all suspended on account of the war.

Section III. In the Huai River Basin.

The Huai River, originating in Honan, running through Honan, Anhui and Kiangsu provinces and emptying into the sea with a total length of more than 800 km., has had a long history of floods and inundations, with an especially severe flood in 1931. Therefore the problem of Huai River is chiefly one of flood prevention, supplemented with navigation, irrigation and power development.

(1) *Flood Control Project.* The Huai River Commission, since its inauguration in 1929, has proposed a complete project, in which the flood water of Huai is regulated to flow both into Yangtse River and east to the sea, and the Hung-tze Lake is utilized as a storage reservoir to diminish the flood discharge down stream, as well as to help navigation and irrigation when necessary. It comprises seven subprojects for the regulation of the whole Huai River Basin.

(2) *Navigation Project.* Within the Huai basin, there are many navigable watercourses, which become non-navigable during low water times. The solution for navigation, as outlined in the said project of the Commission, is to build dams and locks so as to canalize the streams.

a. Navigation Project for the Grand Canal. The Canalization of the Grand Canal in a length of 430 Km. required five locks with dams.

b. Navigation Project for the Huai River proper, leading to the Sea. This channel is led down from Wan-Yuan to Loong-Kou, where it is divided into two routes to the sea. The whole line, 483 Km. long, can be canalized by means of 4 locks and 3 movable dams.

(3) *Irrigation Projects.* The vast area, drained by Huai River is mostly of fertile soil, especially the area to the east of the Grand Canal. It is schematically divided into four irrigation districts as follows:

a. Li-Shia River District. It includes six hsiens with cultivable area of about 2,500,000 acres.

b. Kao-Pao Lakes District. It is situated southeast of Hung-Tze Lake, west of Grand Canal, around a series of lakes, covering cultivable area of about 300,000 acres.

c. Tung-Yang Canal District. It is on both sides of Tung-Yang Canal with cultivable area of about 350,000 acres.

d. The Coastal Reclamation District. This big area, about 600,000 acres along the coast, is harmed by salt water from the sea, and in order to be converted into cultivable soil must be reclaimed with drainage and irrigation systems, and at the same time protected from overflow from the sea.

Also, the land, on both sides of Middle Grand Canal, and to the north of Old Yellow River, comprises an area of about 3,000,000 acres which is also cultivable and in need of irrigation.

(4) *Water Power Development.* The Electric Water power development works, as contained in the complete project, proposed by the Huai River Commission, include the following items:

a. Chiang-Pa Water Power Plant at the mouth of Hung-Tze lake.
b. Wishan Lake Water Power Plant.
c. San River Water Power Plant near the site of the weir.
d. Lin-Kien Water Power Plant near the site of the wier.

(5) *Works Already Executed in the Huai River Basin.* Since the proposal of the complete project in 1932, the Huai River Commission carefully selected several items contained therein for execution. These works, either already completed, or still under construction when the war broke out, will be briefly mentioned in the following paragraphs:

a. Those already completed:

1. Excavation of Chang-Foo River for a length of 31 Kms., which is the main channel for the flood water of Huai River to the sea, and also the transportation line from the Huai to the Grand Canal. This was completed in 1933.

2. Construction of Shao-Pai, Huai-Yin and Liu-Kien Locks with leading channels. All were opened to traffic upon completion in 1936.

3. Construction of Kao-Yu lock, and repairing and strengthening of the west dyke of the Inner Grand Canal, and closing of 27 culverts in the dyke. Work on west dyke was completed in 1935, and Kao-Yu lock completed in 1936.

4. Construction of stone protection works which were formerly composed of mattresses, on the west and east dykes of Inner Grand Canal and repairing of culverts thereon—40 places for dyke protection, and 28 places for culverts and retaining walls. These works were completed in 1936.

5. Improvement of Wei-Chi Weir near Huai-Yin. This was completed in 1937.

6. Excavation of all channels leading to the sea, and the construction of sluices thereon. Excavation and regulation of all these channels were first undertaken by the National Flood Relief Commission after the disastrous flood of 1931, and later continued by the Huai River Commission with sluices, being completed in 1935.

7. Excavation of the Old Yellow River Channel as a passage for the partial discharge of the Huai River to the sea. This work, with the collaboration of the Kiangsu Provincial Government, utilized the labor of the farmers after harvest and was admirably performed in the spring of 1937, in conformity with the proposed plans.

8. Yang-Chuang Regulator. The construction of this regulator began in 1935 and was finished in June 1937.

9. Excavation and Regulation of Liu-Tang River. Being the outlet of the Yi River, the Liu-Tang River was excavated and regulated with farmers' labor, commandeered by the Kiangsu-Provincial Government in 1934. New dykes of 304 Kms. length were built, and shallow channel of 20 Kms. length excavated.

10. The preliminary regulation works on the lower reaches of the Yi River and Shu River. The works, covering a distance of about 80 Kms., were also made by commandeered labor in 1935.

11. Repairing the main dyke around Hung-Tze Lake. The main dyke around Hung-Tze lake from Chiang-Pa to Kao-Liang-Kien were extensively repaired in 1936.

12. Repairing the dykes to the west side of Wishan Lake and those on the Yi River and the Shu River. This work, covering a total length of dyke of 1242 Kms., and dredging more than 4,000,000 cu. m. of earth, was completed in the spring of 1937.

13. Repairing the dykes on the upper and middle portions of Huai River, together with the construction of various culverts. This was undertaken by the National Flood Relief Commission in 1931. The total accomplishment included dyke repairing of 945 Kms., excavating of North Wi River for 26 Kms., and the construction of 66 culverts.

14. The irrigation works at An-Foong-Tang, Anhui. The work was finished in 1937.

15. Excavation of Cho River. Affected by Yellow River, the Cho River had caused floods every year. The work was done early in 1915 by local authorities by dredging up the original channel of the Ssu River, thus getting 100,000 acres of land reclaimed.

1. Excavation of the shallow reaches of Huai River in Anhu province.

2. Construction of additional culverts for the Huai River in Anhui.

3. Construction of San River Regulator with leading channels.

4. Preliminary dredging of the Grand Canal below Liu-Sah for navigation.

5. Construction of the Chow-Man Regulator.

6. Construction of the weir of Liu-Kien at the mouth of Liu-Tang River.

7. Construction of culverts on the Middle Grand Canal near Liu-Kien.

8. Construction of culverts on the Old Yellow River Channel.

Section IV. In the Yangtse River Basin.

The Yangtse River is the largest river in China, and also in Asia. Generally it is beneficial to the people, and is navigable throughout the year for fairly large steamboats. Specifically it sometimes causes flood in its middle or lower portions. Improvement works were mostly applied below Hankow, and considerable literature was published on studies of Tung-Ting and Tai-Hu lakes.

(1) *Flood Control.*

a. Construction and Maintenance of Dykes on the Yangste and Its Tributaries. After the extraordinary flood of 1931, the National Flood Relief Commission through American loans in the form of wheat and flour did remarkable works on dykes. By completing 1832 Kms. of dykes on the main course of Yangtse, 575 Kms. on tributary Kan River, and 340 Kms. on tributary Han-River, it made the main dykes along both sides of Yangtse continuous all the way below Sha-tze.

b. Construction of Sluice and Dam on Hwa-Yang River. Hwa-Yang River, a tributary of Yangtse, drains a basin consisting of a series of lakes between Hupei and Kiangsi provinces. For controlling the water in the drainage area, the Yangtse River Commission constructed a sluice and a dam at its mouth into Yangtse, which were largely completed when the war broke out.

c. Pai-Mao Sluice. Pai-Mao River is the connecting water-course between the Tai-Hu and the Yangtse. A sluice was erected at its mouth into the Yangtse by the said Commission in 1936 for the purpose of checking the back flow of Yangtse high water to the interior land.

(2) *Navigation.* The Whangpoo River, connecting Shanghai to the sea, is the most important navigational route in the Yangtse basin. It is the Whangpoo Conservancy Board which has long taken sole charge of the river, and has made it possible to accommodate sea-going vessels of 9.2 meters draft for passage up to Shanghai.

(3) *Irrigation.* For the reclamation of Kin-Shui area in Hupei province, the Yangtse Commission constructed in 1935 a dam and a sluice on the waterway leading to the Yangtse, which produced very good results.

Section V. In the Pearl River Basin.

Within the Pearl River drainage basin, the excavation of the Lin-Canal made in the Chin Dynasty and the irrigation enterprise of the Han River, made in the Sung Dynasty were both brilliant in history. The following are some conservancy works done in recent decades.

(1) *Flood Prevention.*

a. Kao-Yao and Sung-Loong Protection Works. These works were made on the east bank of the Sung-Loong River to defend an agricultural area of 23,000 acres, being completed in 1927.

b. Yao-Ming Protection Works. Situated at Kao-Ming on the West River, they protect a cultivable area of 20,000 acres, being completed in 1937.

c. Shin-Shin River Protection Works. These works protect an area of 1,000 acres, and were planned to be completed in the summer of 1938.

d. Lu-Poa Regulator. It was constructed at Lu-Poa on the North River in Kwang-tung province for the purpose of reclaiming an area of 36,000 acres. The construction work lasted for four years, from 1920 to 1924.

e. Ma-Shih Protection Works. It is situated at Ma-Shih on the East River, covering an area of about 40,000 acres, and was planned to be completed in 1924.

f. Han-Chih Protection Works. These are to protect an area of 11,500 acres and were completed in 1936.

(2) *Navigation.*

a. Improvement of the Front Navigation of Pearl River. By this, we mean the navigation line in the north branch of Pearl River from Sha-Mei to Whanpoa Harbor. Improvement work was divided into two parts, inside of the harbor and outside of the harbor. The former part was finished before the war.

b. Improvement of the Rear Navigation of Pearl River. By this is meant the part of the estuary on the navigation line between Canton and Chang-Chow. It was largely finished when the war broke out.

c. Excavation of the Navigation Channel at Chon-Chuen. It is an important portion of the navigation route on West River. Work was started but not finished.

d. Regulation of Ssu River and Yu River. Ssu River and Yu River are two important transportation waterways in southern Kwangsi and Western Kwangsi respectively, both being the tributaries of West River. Regulation work on both rivers are already finished.

e. Regulation of the Kwei River. The work has already been finished by the Hunan-Kwangsi Waterways Engineering Bureau, making the time for navigation between Kweilin and Bin-Lo shorter by 50 per cent.

(3) *Irrigation.* As to the irrigation work on Pearl River, great emphasis was given to the drainage of the delta area. Besides, Tung Lake of Wei-Yang on East River, and Foong-Lo-Yuan and Ching-Foo-Yuan on West River were all surveyed and planned for irrigation, but only a part of Foong-Lo-Yuan was executed.

Section VI. Hydraulic Researches.

Since the National Economic Council took charge of the conservancy affairs in the whole country as one of its important functions, in the winter of 1934, it began to organize various river commissions according to their respective drainage areas, and to establish several hydraulic laboratories for research, one at Tientsin and the other at Nanking, but later removed to Chungking.

(1) *Laboratory Tests.*

a. The Central Hydraulic Laboratory. It made various successful tests on construction models and has manufactured different kinds of surveying instruments. The following are some of the activities.

1. Model test for Yang-Chuang Regulator.
2. Model test for San River Regulator.
3. Model test for Ma-Tang section of Yangtse River.
4. Model test for the spillway on Hwa-Yang River.
5. Model test for the sluice of Hwa-Yang River.
6. Model test for the regulation of Chin River section of Yangtse River.
7. Test for the movement of bed load.
8. Manufacture of current meter, sounding meter, tide meter, etc.

b. The First Hydraulic Laboratory at Tientsin. It did many testing works, before the invasion of the enemy, of which some are as follows:

1. Model test for the energy dissipators for the dam of the Kwan-Tin Reservoir on Yung-Ting River.
2. Tests for streams carrying loess silt.
3. Model test for the energy dissipators for the weir at Marco Polo Bridge.
4. Tests for the erosion and transporting force for canals in loess.
5. Tests for permeable dams.

(2) *Hydrological Surveys.* Since the founding of the Republic of China, hydrographic data were generally observed and used for the designs of hydraulic works. According to a census made public by the National Economic Council, there were, in 1934, 1470 rain gauge stations, and 152 hydrological stations in addition to 270 water gauge stations.

(3) *Aerial Surveys.* Aerial Surveys were made in 1935 by the National Economic Council over the flooded areas of Yangtse River and Yellow River with satisfactory results. In the next year, the upper reaches of Yellow River from Shen-Chow to Tung-Kwan and from Tung-Kwan to Pao-Tu were also surveyed with airplanes, producing maps of 1/25000 scale.

CHAPTER III. CONSERVANCY WORKS DONE DURING THE WAR AGAINST JAPANESE INVASION.

Section I. Flood Prevention.

(1) *Construction of a New Dyke Against the Flood Water of Yellow River in Honan Province.* In June of 1938, the southern dyke of Yellow River at Chung-Mei hsien, Honan, was damaged by the enemy, and the river immediately rushed southward through the openings, placing a vast area under water. With the cooperation of Honan Provincial Government, the Yellow River Commission at once built a new dyke, on the west of and against the flooded area, running from the north to the south in a total length of more than 300 Kms., which was planned to be completed in the spring of 1939.

(2) *Dyke Repairing Works in Anhui Province.* The flood water of Yellow River through the damaged dykes as mentioned in the preceding paragraph, rushed forward into several rivers in Anhui, notably the Huai and Yin Rivers, of which the dykes were repaired and strengthened accordingly by the Huai Area Famine Relief Commission. This work was finished in 1941.

Section II. Navigation.

In war time, the communication lines become more important than in peace time. The various conservancy organizations, since they were shifted to the west of the country due to war conditions, have been working hard to improve navigation conditions on various rivers. The following may be mentioned.

(1) *Gold Sand River.* Being the upstream section of Yangtse River, it connects with the Yunnan-Burma Highway at some point in Yunnan and may be regulated as a watercourse of international importance. Its improvement work was began in 1940 by the Gold-Sand River Engineering Bureau on what is called the first section of regulation, from Ipin to Mon-Go.

(2) *Chia-Ling River.* Running southward from Shensi, and connecting with the Yangtse River at Chungking, it is an important waterway, especially in war time. Improvement works on the Chia-Ling River were started in 1939. Those of the Shensi section were finished in 1940, and the Szechuan section are still under way.

(3) *Wu River.* The Wu River runs from Kwei-Chow to Szechuan and empties into the Yangtse, now serving as an important portion of

the communication line between Hunan and Szechuan. In this waterway, navigation is only possible below Shih-Nan, and the regulation of the section from Fow-Ling to Shihnan has been made by the Huai River Commission, with satisfactory results.

(4) *Yuan River and Yu River.* The former is one of the main waterways in Hunan, and the latter empties into it. The improvement of these two rivers consisted chiefly in the blasting of obstructing rocks in the channels. 70 places in the Yuan and 18 places in the Yu were improved.

(5) *Ming River.* It is a main branch of Yangtse River. The Yangtse River Commission started to improve the Ming River in 1940 by making regulation works on various rapids, which are still being carried on.

(6) *Ki River.* Ki River, a branch of Yangtse in Szechuan, has rich coal and iron deposits on its upper reaches. The Huai River Commission undertook the task of its improvement, in 1938, by means of canalization so as to make it navigable throughout the year. Three locks with dams were founded on its tributary, the Pu River by the end of 1939, as the first stage of canalization. The second stage, according to the proposed plans, would consist of 22 locks with dams on its main course, of which eight locks are already finished.

(7) *Yen-Ching River.* It is the chief transportation route for Szechuan salt, obtained from wells, from Tse-Liu-Ching to Tu-Kiang, a length of 73 Kms. A canalization plan was decided upon by the North China Rivers Commission, and the construction work has been started.

(8) *Hung River.* This river is a branch of Gold-Sand River in Yunnan, and began to be improved in 1939, with obstructing rocks blasted off at 22 rapids. The work was finished in 1940 with good results.

(9) *Shih-Shui River.* It is one of the transportation routes for Szechuan salt to Kweichow, but its navigation is very difficult owing to the existence of innumerable rapids. The Huai River Commission began to make improvements in 1941, and works have been going on satisfactorily.

(10) *Ma-Bien River.* Ma-Bien River, a branch of the Ming River, is full of impassable rocks and rapids. Improvement works were started by the Yangtse River Commission in 1941, and have been going on smoothly.

(11) *Ching-Shui River.* It is an important waterway between Hunan and Kweichow, and was improved in 1939 by the Yellow River Commission by doing away with some of its remarkable rapids. The work was finished in 1940.

(12) *Kwei River.* Kwei River in Kwangsi, which connects with the Shiang River through the Lin-Canal, serves as the only transportation route between the two vast drainage basins of the Yangtse and the Pearl

River. For its improvement, the Yangtse River Commission did blasting work at 42 places, and dredging work at 20 places, and constructed weirs at 7 places in the years 1939 and 1940.

(13) *Tu-Liu River.* It is a branch of West River in Kwangsi with a length of 905 Kms. Rapids and rocks made the navigation extremely difficult. Improvement work in the section between Liu-Chow and Chang An was performed early in 1938.

Section III. Irrigation.

Since the war, irrigation works have been greatly emphasized in the western provinces of the country for the obvious purpose of increasing agricultural products to meet the demands of the war situation, and most of them have been subsidized by the Farmers' Bank.

(1) *Irrigation Systems in Shensi.* The Lo-Wei irrigation system, drawing water from the Lo River, covering an effective area of 70,000 acres, was commenced in 1934. Works for the whole system were all completed except one tunnel on the canal which was delayed due to quicksand and underground water. The Mwi-Wei system, as mentioned before, was completed in 1940. Hei-Wei system is still under construction. The Han-Wei system, taking water from the Han River, covering an area of 16,000 acres, was commenced in 1938 and is already completed. The Pao-Wei irrigation system, drawing water from Pao River for an effective area of 19,000 acres was started in 1939 and is also completed. Also the Yu-Wei, Ting-Wei, Hsu-Wei, Nien-Wei and Foong-Wei irrigation systems are all being carried out according to their respective plans.

(2) *Irrigation Systems in Kansu.* The Tiao-Wei irrigation system, receiving water from Tiao River, covers an area of 5,000 acres, commenced in 1935 and was completed in 1940. The Wang-Wei irrigation system, receiving water from the Wang River, irrigating an area of about 5,000 acres around Lanchow, and Yung-Tan was commenced in 1939 and now is completed. The Pu-Wei irrigation system, taking water from the Tiao River, can cover an effective area of 5,000 acres, and is to be completed in 1941. The Shin-Lan Canal takes water from Yellow River and is to irrigate the suburbs of Lanchow with an area of 67,000 acres. It is now under construction.

(3) *Irrigation Systems in Honan.* The Chung-Woo irrigation canal at Lu-Shan shien draws water from Sha River for an area of 1,100 acres and the Ming-Lo canal takes water from the Kien-Lao River for an area of 640 acres. Both having been commenced in 1940, are still under construction. Other canals, such as the Yung-Chi and the Wei-Chi canals at Ni-Yang, the Wei-Sung canal at Sung shien and the Cheng-Ping and the Nien-Ling canals are all about to be executed.

(4) *Irrigation Systems in Szechuan.* In the vast province of Sze-

chuan, there have been built, within the recent three years, many new irrigation canals, notably the Cheng-Ze-Canal of San-Tan, the Loong-Shi canal and the Tien-Shing canal of Mie-Yang, the Li-Chuan canal of Mei-Shan, the Hung-Hwa canal of Chin-Cheng, and the Fo-Chi canal of Chang-Ming. Also the Hwa-Chi canal of Hung-Ya, the North and South canals of Sui-Ning, the Shung-Kon canal of Omei, and the Pei-Wu canal of King-Tang are of irrigational importance, and are mostly near completion.

(5) *Irrigation Systems in Sikang.* The Ching-I canal and the Lu-Kiang canal are the only two completed systems, near Ya-An, covering a total area of about 2,000 acres. Others are to be planned.

(6) *Irrigation Systems in Kweichow.* The whole province of Kweichow being so hilly, it is hard to find any area sufficiently big to warrant irrigation works. The canal of Shiao-Loong district at Ting-Feng is probably the only completed irrigation canal ever built. Another district near Tu-Yun is progressing with irrigation works.

(7) *Irrigation Systems in Yun-Nan.* The Wen-Kon canal of Ni-Liang and the Cha-Yuan canal of Mei-Lur are already completed. Also seven other canals for irrigation are under construction.

(8) *Irrigation Systems in Kwangsi.* The Ho-Kiang canal of Li-Pu and Lo-Shu canal of Ni-Shan, covering a total area of more than 6,000 acres were both completed; while six other canals are under construction, and another 23 places are to be surveyed and planned. It has been hoped to increase the agricultural area by 230,000 acres through the process of irrigation within six years.

Section IV. Hydraulic Researches.

(1) On account of the war, the Central Hydraulic Laboratory, as mentioned before, removed to Chungking in Dec. 1937, to continue on its original activities. It established two laboratories, the Pan-Chi Hydraulic Laboratory and the Shih-Men Hydraulic Laboratory on both sides of Chia-Ling River in the following year. Two other laboratories were also established in 1940 at Kuming in Yun-Nan, and Wu-Kon in Shensi, and still another laboratory was installed at Kwan shien in Szechuan in 1941 to deal with different or local problems. So far many model tests on various kinds of proposed hydraulic structures have been made by these laboratories, together with several silt and erosion tests.

(2) *Soil Tests.* The Central Hydraulic Laboratory installed at Pan-Chi a soil testing laboratory in 1940. Its works included boring tests, tests on physical characteristics of soil, and model tests with loess problems as its chief function. It has successfully performed many tests on the mechanical analysis of soil.

(4) *Hydrological Survey.* Since the war, the Central Hydraulic Laboratory has started to establish many new hydrological stations in

the western provinces of the country to meet the demands for waterway regulations and irrigation promotions.

(5) *Manufacture of Hydrographic Appliances.* The Central Hydaulic Laboratory established in 1940 a factory at Chungking to repair and manufacture different kinds of hydrographic appliances, such as current meters, plane tables, etc., with satisfactory results.

CHAPTER IV. POST-WAR CONSERVANCY REHABILITATION PLAN.

Section I. General Principle and Suggested Plan.

(1) *Aim.* The chief aim of the post-war rehabilitation plan will be to do away with flood disasters, to enhance navigation, to increase agricultural products and to develop industrialization. With this object in view, the hydraulic undertakings, as set forth by the Commission for the Study of the Industry Plan of Dr. Sun Yat-Sen, consists of four classes, that is, flood prevention, navigation, irrigation, and water power, which are to be separately outlined and shall be carried out in different periods. It is of course a big task, and the available data at hand are not yet sufficient for detailed plans. Generally speaking, the work for flood prevention will be to close the openings and repair the damaged portions of the river dykes; the work for navigation, to regulate or canalize the channels for the most important watercourses; the work for irrigation, to irrigate or reclaim large needed areas by drawing water from natural waterways; and the work for water power to develop hydroelectric power by utilizing the water head at natural waterfalls or river dams.

(2) *Scope and Capacity.* Based upon the principle, mentioned above, China's post-war conservancy works will be of the following scope and magnitude.

a. Flood Control. For the systematic regulation of the principal waterways, such as the Yangtse River, Yellow River, Huai River etc., to prevent the occurrence of floods, dykes and reservoirs must be properly constructed, to be supplemented with dredging works. It is now estimated that it will be necessary to build twenty reservoirs, and construct 18,660 Kms. of dykes.

b. Navigation. It is expected to complete the national navigation system within the coming twenty years for the promotion of transportation and culture. It comprises the following:

1. To improve natural waterways and existing canals, navigable for steamers of 1 to 2 meters drafts, for 30,000 Kms. 10,000 Kms. navigable for those of 2 to 5 meters drafts, and 2,500 Kms. navigable for those of 5 to 8 meters draft.

2. To improve waterways and canal for 500,000 Kms. navigable by wooden boats.

3. To excavate new canals for 5,000 Kms. navigable by steamers.

4. To develop 1,200 inner river harbors, of which 50 shall be of first class, 150 of second class, and 1,000 of third class.

c. Irrigation. Beside the existing irrigated area of about 3,000,000 acres, a further area of about 35,000,000 acres shall be developed with irrigation works.

d. Water Power. All the available water power in the mountainous provinces in west China shall be carefully developed to meet the industrial demands. The total amount of hydro-electric power, that has been or is being developed, amounts only to 15,000 kilowatts, and it is expected to further develop 10,000,000 kilowatts.

(3) *Division of Districts and Periods (each of 5 years).*

Conservancy improvements should be consistent with those on other lines, and adaptable to the natural environment for the joint promotion of people's livelihood and national defense. Their execution shall be divided into districts, and carried out in periods (each of 5 years) somewhat as follows:

a. Flood Prevention.

1. Yellow River District. Flood prevention works in this district, including Yellow River, Shin River, I River and Lo River, shall be performed in the first and second periods, and shall consist of dyke construction, bank protection, reservoirs, and channel dredgings.

2. Huai River District. The works in this district, including Huai River, Yi River, Ssu River, and the Grand Canal, shall be carried out in the first and second periods and shall consist of dyke construction, sluices, reservoirs, and channel excavations.

3. North District. The works in this district, including 5 main rivers in Hopei, the Lur River and the Chi-Yung River, shall be performed in the first and second periods, and shall consist of the same kind of works as in the preceding district.

4. Yangtse River District. The works in this district, including Yangtse River with its tributaries, and Tung-Ting, Poyang, and Tai lakes, shall be performed in the first and second periods, and shall consist of dyke construction, bank protection, sluices, reservoirs, dredgings, and lake preservance.

5. Pearl River District. The works in this district, including Pearl River with its delta and East, West, and North rivers, shall be performed in the first and second periods, and shall consist of the same kinds of works as in the Huai River District.

6. South-East District. The works in this district, including Tsien-Tang River, Ming River, Ou River and other rivers in Chekiang and Fukien provinces, shall be performed in the second and third periods, and shall consist of dyke construction, bank protection, reservoirs and sluices.

7. North-East District. The works in this district, including Amur River, Sungari River, Liao River, and other rivers in northern-eastern provinces, shall be performed in the second and third periods, and shall consist of the same kinds as in the preceeding district.

8. North-West District. The works in the district, including Shu-Shui drainage basin, and other rivers, not included in the Yellow River drainage basin, shall be performed in the fourth period, and shall consist of the same kinds as in the preceding district.

b. Navigation. The national navigation system is planned according to the natural drainage areas of the various rivers, and also divided into eight districts, the same as those for flood prevention works. The element of the different districts are shown in the following table:

No. of Dist-rict	Name of District	Length of Waterways Regulated in Kms.				No. of Harbours Developed			Period @ 5 years	Remarks
		For Draft 5–8 m.	For Draft 2–5 m.	For Draft 1–2 m.	For Wooden Boats	1st. Class	2nd. Class	3rd. Class		
1	Yangtse River	1,830	3,460	7,390	80,000	24	60	300	1st and 2nd	Each period for 5 years
2	Huai River	—	1,400	2,220	80,000	4	15	150	1st and 2nd	
3	North	70	1,140	1,650	50,000	4	10	50	2nd and 3rd	
4	Pearl River	170	1,270	2,660	30,000	4	20	150	2nd and 3rd	
5	Yellow River	—	—	5,080	50,000	—	10	50	2nd and 3rd	
6	South-East	110	380	1,930	30,000	7	15	150	3rd and 4th	
7	North-West	—	—	900	50,000	—	—	30	3rd and 4th	
8	North-East	320	650	2,370	30,000	7	20	120	3rd and 4th	
	Total	2,500	8,300	24,200	400,000	50	150	1,000		

c. Irrigation. According to the latest census, the total acreage of the cultivated land in the whole country amounts to about 230,000,000 acres, of which 41,000,000 acres, or about 18 per cent., are still in lack of proper irrigation, and will be improved or reformed with one of the following processes: (1) by drawing water from natural waterways, (2) by pumping with electric or other motive power, (3) by drawing water from reservoir, (4) by taking water from melted snow on high mountains, (5) by drilling wells, (6) by excavating ponds, and (7) by silting. Works shall be carried out in eight districts, and four periods, each for 5 years, as in the table shown at top of page 419.

d. Water Power. Water power is most abundant in the western provinces, such as Szechuan, Sikang, Kweichow and Yunnan, due to their mountainous topography. Or in other words, the Yangtse River and the Yellow River possess the highest capacity so far as water power is concerned. According to statistical reports, the total water power that has been or is being developed amounts to only 15,000 kilowatts, so we have still vast possibilities for water power development, which is

No. of District	Name of District	Cultivated Area to be irrigated in acres	Periods @ 5 years	Locations and Remarks
1	North-West	9,200,000	1st and 2nd	Kansu, Ningsha, Sinkiang, Chinghai, Suiyuan, Shansi
2	North	5,700,000	1st and 2nd	Shansi, Charhar, Hopei, Shangtung, Honan
3	South-West	2,400,000	1st and 2nd	Szechuan, Sikang, Kweichow, Yunnan
4	North-East	2,000,000	2nd	Liaoning, Kirin, Heilongkiang, Jehol
5	Central	21,300,000	2nd, 3rd* and 4th	Hunan, Hupei, Kiangsi, Anhui, Kiangsu, Chekiang
6	South	400,000	3rd and 4th	Fukien, Kwangtung, Kwangsi
7	Mongolia	—		Data not sufficient
8	Tibet	—		Data not sufficient
	Total	41,000,000		

* Irrigation Works in this district should be coupled with river improvement works, hence they are not started in the first period.

roughly estimated to be 10,000,000 kilowatts,* and will be gradually carried out in consistence with the industrial needs, and divided in different districts and periods as per the following table:

No. of District	Name of District	Water power to be developed in kilowatts	Periods @ 5 years	Localities
1	Szechuan Sikang	2,300,000	1st and 2nd	Szechuan, Sikang
2	Yunnan-Kweichow	2,300,000	1st and 2nd	Yunnan, Kweichow
3	Hupei-Hunan	1,900,000	2nd and 3rd	Hupei, Hunan
4	Kwang-tung Kwangsi	800,000	2nd and 3rd	Kwangtung, Kwangsi
5	North-West	900,000	3rd and 4th	Kansu, Ningsha, Shansi, Shensi
6	South-East	1,000,000	3rd and 4th	Kiangsi, Chekiang, Fukien
7	North-East	800,000	3rd and 4th	Liaoning, Kirin, Heilungkiang
	Total	10,000,000		

Section II. Preparatory Steps.

(1) *General Survey and Reconnaissance on All Rivers in the Country.*

a. To organize survey and reconnaissance parties to work on rivers, especially those for which necessary data are lacking.

b. To establish more hydrological stations.

c. To promote hydraulic laboratory and research activities.

(2) *Concrete Projects for All River Systems.*

Concrete working projects shall be formulated on all important waterways in the country, except the Huai River and the Yung-Ting River, of which complete plans have been made and published.

* This article was written before the Yangtse Gorge Project was proposed.

(3) *Standardization of Designs.*

All elements in designs shall be standardized by an authorized body, composed of qualified experts, to avoid future irregularities.

(4) *Preparation and Training of Personnel.*

a. Preparation of technical men of middle and high classes. The conservancy engineering course will be specially added to universities and colleges. According to "the fortune of China," written by President Chiang Kai-Shek, within the first ten years of post-war reconstruction, there will be needed 14,000 engineers, hydraulic, civil and mechanical, and 60,000 draftsmen and foremen. Those with superior abilities will be sent abroad for further studies.

b. Establishment of short-term training schools. Training schools of short terms will be extensively established in provinces and hsiens to train up general personnel for the maintenance of river works and irrigation systems more or less of an administrative character.

(5) *Utilization of Soldiers' Service and Commandeered Labor.* This is of paramount importance, especially in the period immediately after demobilization. Detailed plans will be worked out to utilize soldiers' services and people's labor for the execution of river work, which will consist chiefly of earth works.

(6) *Funds.*

a. Special Allotment. The expenditures for these various river works will be defrayed from the Central Government's treasury for nationwide projects, and by local governments or paid by people directly benefited for local projects. Special allotments must be ready before the start of the work.

b. Foreign Capital or Loans. For the post-war reconstruction plans of river works, foreign loans or debentures are expected and welcomed. The repayment of principal and interest will be made by the enterprises concerned, or the people benefited. If the revenue thus collected proves not sufficient for the repayment, the land tax will be used.

THE FRANKLIN INSTITUTE

STATED MONTHLY MEETING, LECTURE HALL 8:15 P. M., WEDNESDAY, OCTOBER 16, 1946.

The stated monthly meeting of The Franklin Institute, held on Wednesday, October 16, at 8:00 P.M., was called to order by Mr. Richard T. Nalle, Vice President, acting in President Redding's capacity. There were approximately four hundred present.

The minutes of the previous meeting on May 15 had been printed in full in the June number of the JOURNAL and were approved as printed.

The Secretary gave his report which was as follows:

The elections to membership for June, July, August, and September are as follows:

Active	203
Associate	83
Student	63
Total membership as of September 30, 1946	5500

Mr. Nalle then introduced the speaker of the evening, Dr. Harvey Fletcher, Director of Physical Research at the Bell Telephone Laboratories, Murray Hill, N. J. Dr. Fletcher spoke, with many demonstrations on the "Pitch, Loudness, and Quality of Musical Tones" and the relationship between the intensity, the frequency of vibration and the overtone structure of muscial tones and their corresponding psychological characteristics.

At 9:30, Dr. Fletcher had to leave, but he left his three assistants, Messrs. Balashek, Oncley, and Soffel to conduct an open meeting of questions and answers. This proved both profitable and explanatory. The meeting was adjourned at 10 o'clock.

LIBRARY NOTES.

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 9 × 14 inches is thirty-five cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from 9 A.M. until 5 P.M., Wednesdays and Thursdays from 2 P.M. until 10 P.M.

RECENT ADDITIONS.

AERONAUTICS.

SHERWOOD, A. WILEY. Aerodynamics. 1946.

AGRICULTURE.

HALL, A. D. The Soil. 1945.

ASTRONOMY.

ABBOTT, CHARLES GREELEY. The Earth and the Stars. 1946.

CHEMISTRY AND CHEMICAL TECHNOLOGY.

ARMSTRONG, E. F. AND L. M. MIALL. Raw Materials from the Sea.
CAMM, FREDERICK J. Newnes Plastics Manual. 1945.
FINDLAY, A. Introduction to Physical Chemistry. 1944.
FOWLER, GILBERT J. An Introduction to the Biochemistry of Nitrogen. 1934.
GARDNER, H. A. AND G. G. SWARD. Physical and Chemical Examination of Paint, Varnishes. 1946.
GNAMM, HELLMUT. Die Fettstoffe des Gerbers. 1943.
GYNGELL, ERIC S. Applied Chemistry for Engineers. 1944.
HARVEY, H. W. Recent Advances in the Chemistry and Biology of Sea Water. 1945.
JORGENSON, A. P. C. Practical Management of Pure Yeast. 1936.
LOWRY, THOMAS M. Inorganic Chemistry. 1942.
MCINTOSH, JOHN. Industrial Alcohol. 1923.
MANN, F. AND SAUNDERS B. Practical Organic Chemistry. 1946.
MORTON, AVERY A. The Heterocyclic Compounds. 1946.
SMITH, LEROY H. Synthetic Fiber Developments in Germany. 1946.
TROENSEGAARD, N. On the Structure of the Protein Molecule. 1944.
WHITTAKER, C. M. AND C. C. WILCOCK. Dyeing with Coal Tar Dyestuffs. 1942.

ELECTRICAL ENGINEERING.

BROTHERTON, M. Capacitors. 1946.
Coyne Electrical School. Electronics for Electricians and Radio Men. 1945.
GROVER, FREDERICK W. Inductance Calculations. 1946.

ENGINEERING.

Cooper Union. A Guide to the Literature on the History of Engineering. 1946.
HETENYI, M. I. Beams on Elastic Foundations. 1946.
MORLEY, ARTHUR. Strength of Materials. 1945.
STEEDS, WILLIAM. Engineering. Materials. 1943.

FOOD.

BARTLETT, ROLAND W. The Milk Industry. 1946.

MATHEMATICS.

BLISS, GILBERT AMES. Lectures on the Calculus of Variations. 1946.
BURNSIDE, WILLIAM SNOW. Theory of Probability. 1936.
COOLIDGE, J. L. An Introduction to Mathematical Probability. 1942.
FITE, WILLIAM BENJAMIN. Advanced Calculus. 1938.
MCKAY, HERBERT. The World of Numbers. 1946.
ROBERTS, W. R. W. Elliptic and Hyperelliptic Integrals and Allied Theory. 1938.

MECHANICAL ENGINEERING.

BEVAN, THOMAS. The Theory of Machines. 1944.
CHAPMAN, W. A. J. Workshop Technology. 2 volumes. 1945.
HINMAN, C. W. Practical Designs for Milling, Drilling and Tapping Tools. 1946.
LOW, BEVIS B. Engineering. Mechanics. 1943.
MORLEY, ARTHUR. Mechanics for Engineers. 1943.
STEEDS, WILLIAM. Mechanism and the Kinematics of Machines. 1945.

METALLURGY.

BURN, DUNCAN LYALL. The Economic History of Steelmaking. 1940.
JOHNSON, F. Heat Treatment of Carbon Steels. 1946.

MILITARY ENGINEERING.

CAMPBELL, LEVIN H. The Industry-Ordnance Team. 1946.
COLVER, E. DE W. S. High Explosives. 1938.
FISHER, GEORGE J. B. Incendiary Warfare. 1946.

NAVAL ARTS AND SCIENCE.

CORNELL, F. M. AND A. C. HOFFMAN. American Merchant Seaman's Manual. 1946.

OPTICS.

BOWEN, EDMUND JOHN. The Chemical Aspects of Light. 1946.

PHARMACY AND HYGIENE.

FLEMING, ALEXANDER. Penicillin. 1946.

PHYSICS.

LAURENCE, WILLIAM L. Dawn Over Zero. 1946.

SCIENCE.

DAMPIER, WILLIAM CECIL. A Shorter History of Science. 1945.

TEXTILES.

BENDURE, Z. AND G. PFEIFFER. America's Fabrics. 1946.
MORTON, WILLIAM ERNEST. An Introduction to the Study of Spinning. 1937.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Ribonucleinase and Non-Specific Phosphodiesterase in Rat and Rabbit Blood and Tissues.—CHARLES A. ZITTLE AND ELIZABETH H. READING. A manometric method for estimating crystalline ribonucleinase was devised by Bain and Rusch (1), and applied to biological material. This method was subsequently used by others (2) who in later studies (3, 4) showed that a purified non-specific phosphodiesterase from calf intestinal mucosa could be estimated by the same procedure. This finding raised the question as to which enzyme was being measured in biological material. The two enzymes were distinguished (3) by the large amount of substrate required for the full activity of the former and the small amount required for the latter. This property has been used to differentiate these enzymes in the blood and tissues of rat and rabbit.

EXPERIMENTAL.

The preparation of the crystalline ribonucleinase (2) and the purified phosphodiesterase (4) has been described as well as details of the manometric procedures (2, 4). The reaction of these enzymes with several concentrations of ribonucleic acid is shown in Fig. 1. There is a slight activity of the ribonucleinase even with a small amount of nucleic acid, which has been kept in mind in considering the data obtained with biological material. The reactivities of the enzymes with a small and a large amount of nucleic acid have been expressed on a percentage basis in Table I; for the non-specific phosphodiesterase it is 100 per cent., for ribonucleinase it is about 10 per cent. Conclusions as to the amounts of these enzymes in blood and tissues are based on comparisons with these percentages.* Since this percentage tends to increase with decrease in the amount of the ribonucleinase, in the assays amounts of tissue were chosen which gave reactivities approximating that of the pure ribonucleinase used, i.e., 50 c.mm. per 10 minutes.

The blood and tissues were obtained and prepared for analysis as described (2). Experiments were performed with several concentrations of the blood or tissue and 150 or 6 mg. of nucleic acid.

* It has been assumed that the ribonucleinase and phosphodiesterase are the only enzymes measured by the manometric procedure with nucleic acid, however the deaminases for nucleic acids reported by Greenstein and Chalkley (5) would interfere by forming NH_3 which would absorb CO_2. Since the enzymes reported were active with small amounts of nucleic acid (5 mg. with 160 mg. tissue), any correction would probably apply to the results with both 150 and 6 mg. of nucleic acid. A recent paper (11), however, makes it appear improbable that the deaminases act on the intact nucleic acids.

DISCUSSION.

In the original application of the ribonucleinase method Bain and Rusch (1) referred to the possible involvement of phosphatase as follows: "Bolomey and Allen have reported that the action of a non-specific phosphatase preparation upon nucleic acid is increased 50 to 150 per cent. following preliminary treatment of the acid with ribo-

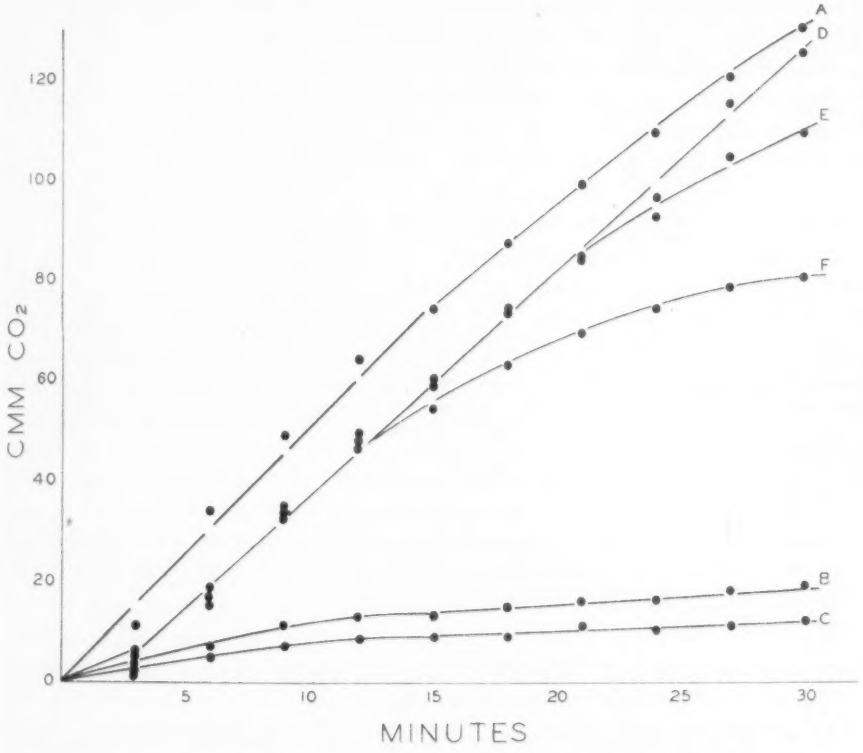


FIG. 1. Action of ribonucleinase and non-specific phosphodiesterase with several concentrations of ribonucleic acid in terms of CO_2 evolved from $NaHCO_3$ buffer. Curve A, Ribonucleinase, 12γ, with 150 mg. ribonucleic acid; Curve B, with 5 mg. ribonucleic acid; Curve C, with 3 mg. ribonucleic acid. Curve D, Phosphodiesterase, 2.0 mg., with 150 mg. ribonucleic acid; Curve E, with 5 mg. ribonucleic acid; Curve F, with 3 mg. ribonucleic acid. Each flask contained 1.0 cc. of 0.1 M $NaHCO_3$, nucleic acid, and the enzyme in the side arm. Water was added to make the final total volume 3.5 cc.

nucleinase. Fluoride and cyanide have been reported to inhibit acid and alkaline phosphatase respectively and their inhibitory action on the phosphatase activity of various homogenates at pH 7.4 was confirmed in this laboratory. . . . These data show that M/150 NaF and NaCN do not inhibit crystalline ribonucleinase activity and that there is no significant difference between the activity of the inhibitor treated and

TABLE I.

Reactions of Rat and Rabbit Blood and Tissues Compared with Those of Ribonucleinase and Phosphodiesterase with Several Concentrations of Nucleic Acid.

Substance tested	Ribonucleic acid	Reactivity *	Comparative reactivity enzyme with 5 or 6 mg.:150 mg. nucleic acid
	mg.	*c.mm. CO_2/10 min.*	*per cent.*
Ribonucleinase, crystalline	150	50 †	
Ribonucleinase, crystalline	5	4 †	8
Phosphodiesterase, purified	150	45 †	
Phosphodiesterase, purified	5 and 3	45 †	100
Spleen, rat	150	44	
Spleen, rat	6	4	11
Spleen, rat plus 1.25 mg. phosphodiesterase	150	87	
Spleen, rat plus 1.25 mg. phosphodiesterase	6	38	44
Small intestine (mucosa), rat	150	26	
Small intestine (mucosa), rat	6	14	54
Pancreas, rat	150	163	
Pancreas, rat	6	14	9
Kidney, rat	150	11	
Kidney, rat	6	11.5	105
Blood, rat	150	4.1	
Blood, rat	6	0.5	12
Bone marrow, rabbit	150	23	
Bone marrow, rabbit	6	5	22
Spleen, rabbit	150	47	
Spleen, rabbit	6	9	19
Blood, rabbit	150	8.3	
Blood, rabbit	6	1.3	16

* The reactivities are: for the amounts of the purified enzymes used for Fig. 1; for blood, per cc.; for tissue (wet weight), per 100 mg. The reactivities are based on the release of CO_2 at the expiration of 10 minutes because of the initial dilution effects.

† Read from Fig. 1.

natural homogenates, indicating that non-specific phosphatases are not an important source of error in the assay."

It is not clear how Bain and Rusch pictured that phosphatase might interfere; usually the term "phosphatase" is applied to the enzyme hydrolyzing monoesters of phosphoric acid. Such esters involve the tertiary phosphoric acid group and hydrolysis of them would not release CO_2 in the above assay method since the tertiary phosphoric acid group is a weak acid. Phosphatase preparations, however, are capable of hydrolyzing ribonucleic acid (3, 6, 7) and secondary phosphoric acid groups, the group measured by the above method, must appear at some stage of the hydrolysis when diesters of phosphoric acid are split. This has been found to be the case and the above method serves to assay phosphatase preparations for their phosphodiesterase content (3). These preparations do not contain ribonucleinase, as shown by the effect of temperature (6) and degree of association of the enzyme with the substrate (3). The degree to which the above phosphodiesterase participates in the ribonucleinase assay has been unknown since we

have found that M/150 NaCN (final concentration), used by Bain and Rusch, is not inhibitory to the phosphodiesterase activity of our enzyme preparation. The present studies show that both enzymes are present in blood and tissues and that the relative content of ribonucleinase and phosphodiesterase varies.

The data in Table I show that in rat spleen and pancreas the predominant enzyme measured by this procedure is ribonucleinase. Addition of phosphodiesterase to the rat spleen showed that there was nothing in the tissue which interfered with this enzyme. Rabbit bone marrow and spleen apparently contain some phosphodiesterase in addition to the ribonucleinase. Rat intestinal mucosa contains equivalent amounts of both enzymes, in terms of activity. Phosphodiesterase is predominant in the rat kidney. In both rat and rabbit blood the predominant enzyme measured is ribonucleinase.

Estimations of the non-specific phosphodiesterase in animal tissues have not hitherto been available. Assuming tentatively (3) that the phosphodi- and phosphomonoesterase activities are inherent in one enzyme, a comparison of the present data with the phosphomonoesterase (alkaline phosphatase) activity of several tissues would be of interest. Kidney and intestinal mucosa are much richer in phosphomonoesterase than any other tissue (8); intestinal mucosa has usually been the tissue of choice in preparing this enzyme and it has been used in the present studies for preparing the diesterase. The data in Table I show that these tissues are especially rich in diesterase. Recently (9) the alkaline phosphatase in rat pancreas has been shown to be negligible. Little or no diesterase is found in this tissue (Table I).

The amounts of phosphodiesterase that are represented by the assay values must remain unknown until the pure enzyme is available. Several milligrams of the present purified material are required for a satisfactory assay. The low reactivity of this enzyme is not unexpected, if, as suggested (3), the ability to hydrolyze diesters is a concomitant property of the phosphomonoesterase. Phosphatase preparations are approximately one hundred times more reactive with monoesters than diesters of phosphoric acid (3, 6). This difference is probably correlated with the difference in acid strength of the two types of ester (10).

Summary. Ribonucleinase and non-specific phosphodiesterase have been measured manometrically by the use of several concentrations (150 and 6 mg./3.5 cc.) of ribonucleic acid as the substrate at pH 7.5—the former enzyme was found to be most active with the higher concentration of nucleic acid whereas the latter was active with both concentrations of nucleic acid. Variable amounts of both enzymes were found in rat and rabbit blood and tissues; pancreas was outstanding in containing large amounts of ribonucleinase and little or no phosphodiesterase, kidney on the other hand contained only phosphodiesterase.

REFERENCES.

(1) BAIN, J. A., AND RUSCH, H. P., *J. Biol. Chem.*, **153**, 659 (1944).
(2) ZITTLE, C. A., AND READING, E. H., *J. Biol. Chem.*, **160**, 519 (1945).
(3) ZITTLE, C. A., *J. Franklin Inst.*, **241**, 379 (1946).
(4) ZITTLE, C. A., *J. Biol. Chem.*, in press.
(5) GREENSTEIN, J. P., AND CHALKLEY, H. W., *J. Natl. Cancer Inst.*, **6**, 61 (1945).
(6) SCHMIDT, G., AND THANNHAUSER, S. J., *J. Biol. Chem.* **149**, 369 (1943).
(7) COHEN, S. S., AND STANLEY, W. M., *J. Biol. Chem.*, **142**, 863 (1942).
(8) GREENSTEIN, J. P., *J. Natl. Cancer Inst.*, **2**, 511 (1941–42).
(9) JACOBY, F., *Nature*, **158**, 268 (1946).
(10) KING, E. J., AND DELORY, G. E., *Biochem. J.*, **33**, 1185 (1939).
(11) Greenstein, J. P., Carter, C. E., and Chalkley, H. W., *Arch. Biochem.* **11**, 307 (1946).

BOOK REVIEW.

PROCEEDINGS OF THE MEXICAN-AMERICAN CONFERENCE ON INDUSTRIAL RESEARCH, September 30–October 6, 1945. 176 pages, tables, 15×23 cms. Chicago, Armour Research Foundation, 1946. Price $2.50. Paper.

From September 30 to October 6, 1945 there was held in Chicago the Mexican-American Conference on Industrial Research under the auspices of the Armour Research Foundation of Illinois Institute of Technology. The Foundation had undertaken some research investigations for the Banco de Mexico, and during the course of the investigations, the need became apparent for holding international discussions on scientific education, fundamental research, nd industrial research with leaders of industry and finance of Mexico and the United States. The conference was held in Chicago and included not only talks but visits to laboratories so that the Mexican visitors were actually able to see research in action.

Various types of research were presented: "fundamental research in college and university laboratories, industrial research conducted by technical foundations devoted to the interests of public service, research supported by industrial associations, and research maintained in the private laboratories of industry."

The Mexican delegation included government engineers and representatives of banking, industry and commerce, and the roster of speakers included many names prominent in pure and applied science. The present volume contains the record of these speeches with some of the accompanying discussion.

A paper by Harold Vagtborg outlined *The Industrial Research Pattern of the United States*, and was followed by others dealing with *The Integration of Industrial Research and Education* by Linton E. Grinter and *Fundamental Research in College and University Laboratories* by Walter Bartky. In view of the recent establishment of The Franklin Institute Laboratories for Research and Development, the two most interesting articles to this reviewer were those describing the activities of two of the similar non-profit institutions engaged in industrial research. A discussion of the Mellon Institute formed the principal point of departure of the paper by its director, Dr. E. R. Weidlein, *The Organization, Management, and Effectiveness of Institutional Research*. The director of the sponsoring organization, Dr. Jesse E. Hobson, discussed *The Armour Plan for Industrial Research*, and pointed out ways in which its approach to the problem differed from that of the Mellon Institute. Industry was represented by Dr. L. A. Hawkins of the General Electric Company and Dr. Gustav Egloff of the Universal Oil Products Company who reviewed some of the research activities of their companies.

It is not possible here to list all the papers, but there were six devoted to various phases of agricultural research, three to standards and their importance, and several of the concluding papers outlined the possibilities of industrial development on the international front. At the conclusion of the conference, the Mexican guests recorded their reactions to what they had seen and heard.

The entire volume is a stimulating group of papers on the importance and methods of industrial research. The Armour Research Foundation is to be congratulated upon its vision in sponsoring such a conference, important in itself but also with very definite overtones of international good will.

GEORGE E. PETTENGILL.

THE SCIENCE AND ART OF PERFUMERY, by Edward Sagarin. 268 pages, illustrations, 14×20 cms. New York, McGraw-Hill Book Co., Inc., 1945. Price $3.00.

The term "essential oil" is derived from the literal meaning of the word "essential"; that is, pertaining to essences. There is an aura of romantic mystery about essential oils, one that has surely added to the enchanting delight of perfumery. Strange sounding names of plants, intranslatable into our language, are complemented by the place of inaccessible and unheard-

of spots on earth, associated in the public mind with commerce in essential oils. Other names come directly from delicious-smelling flours, bringing to mind the fresh garden aroma of jasmin, and hyacinth, narcissus and violet leaf.

It is true that there is not a spot on earth without at least a minor industry in essential oil production. But, by and large, a few communities have become world centers in the traffic in these products. The growing of plants and the production of the oil become the big industries of importance to the people.

Today perfumes are found in ointments, creams, cosmetics of all types, flavors, insecticides, tooth pastes and in literally thousands of other types of products. Perfumery is the science and art of odor. It is concerned with the creation of new odors, the duplication of others, whether they be from nature or from the laboratory. It changes the odors of materials, usually to make them smell more pleasing, sometimes to abolish the smell entirely, and sometimes to make it quite obnoxious.

The story as told in this book includes historic, scientific, commerical and popular details of the industry. Anyone can read it as a source of general knowledge, but it is intended especially for those in the odor business, the perfumer, the chemist, the salesman, the purchasing agent, the executive, etc. Included in it is a discussion of various phases of accumulated literature on the subject. The subject index in the back adds to the value of the work as a reference.

UNDERSTANDING MICROWAVES, by Victor J. Young. 385 pages, illustrations, 15×22 cms. New York, John F. Rider Publisher, Inc., 1946. Price $6.00.

As science progresses, it becomes increasingly difficult to translate techniques for use of those not well equipped. Yet, there is an increasing need for this. Fields of activity open for many such workers, which involve much besides that which is directly concerned with the design of apparatus. No better illustration of this exists than in the field of microwaves, for there is no doubt that radio technique of tomorrow, as well as considerable present interest, is with waves measured in centimeters and millimeters. The book at hand is made for those with a small knowledge of the conventional uses of electricity plus a willingness to think in terms of physical ideas and experiments.

The first section of the book starts with very elementary concepts of the nature of electricity and frequency. The stationary charge, magnetostatics, and alternating currents are described leading to the subject of transmission lines. The rule of avoiding mathematics is broken by the one section which dwells on Maxwell's equations. There follows a good description of wave guides, and the subject of resonant cavities by first discussing the action of a resonant circuit in a Hartley oscillator. In treating on antennas it is pointed out that the problem of constructing the most efficient reflecting surface behind a dipole radiator, so as to cause a large fraction of the energy to travel forward in a narrow beam, is similar to the one which is encountered in building a searchlight reflector or a reflecting telescope. The final chapters of Section I of the book dwell on microwave oscillators, and radar and communication.

A rather unique part of such a work is Section II on terminology. There is listed here alphabetically, microwave terms with full explanations of them, ideas and theorems primarily intended to give discussions and introductions to concepts rather than rigorous definitions. Some sentences shown in italics give summaries of each paragraph.

A great deal of effort has been put forth in this book. The descriptions and explanations coupled with helpful drawings with references to formulae without actually using mathematics make this book valuable in considering radio waves shorter than 10 centimeters. Engineers as well as service and operation workers should gain much from its use.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Nucleonics. 38 pages, drawings, 21 × 28 cms. Washington, D. C., Progress Press, 1946. Price $1.00 (paper).

Radio's Conquest of Space, by Donald McNicol. 374 pages, illustrations, 14 × 22 cms. New York, Murray Hill Books, Inc., 1946. Price $4.00.

CURRENT TOPICS.

Steel Wire Manufacture.—A triumph in the art of manufacturing quality steel wire has been achieved by the American Steel and Wire Co., U. S. Steel subsidiary, in producing great amounts of valve spring wire so vital to the efficient operation of America's postwar automobiles.

Prior to the outbreak of World War II, virtually all of the steel rods for reduction into wire for automotive valve springs were imported from Sweden. In that country, extremely high grade ores were readily available. Swedish iron plants, for the most part, were small units utilizing charcoal rather than coke for fuel, resulting in a cleaner iron and a cleaner steel. Rolling mills were small, hand-operated units which, while producing comparatively small tonnages, permitted extreme care to be exercised in producing steel rods with virtually no seams or scratches. Extremely high surface qualities are of great importance when attempting to avoid failure of the material used in springs which are compressed and released 4,000 times each minute.

With the advent of the war, in 1939, shipments from Sweden were cut off and metallurgists of the American steel industry, including American Steel and Wire, were faced with the problem of replacing that source of high-grade steel rods. The result was that a product superior even to the Swedish material was developed for use in the last of the pre-war automobiles. It played an important war-time rôle in keeping in operation the jeeps, peeps, half-tracks, tanks, and other mobile equipment so vital to the winning of the war.

Extreme care is exercised in choosing raw materials for this premium steel product. Only carefully graded pig iron and steel scrap are used, and improved steel-making practices have been developed. Special heat treating methods, together with close rolling and drawing controls, also contribute toward producing a high-quality steel wire free from surface imperfections and possessing other physical properties rendering it more than adequate to make American automobile manufacturers independent of the foreign source of supply.

R. H. O.

New Method of Cleaning Aluminum Before Welding with Inert-Arc Method.—In searching for a satisfactory method of cleaning aluminum in preparation for welding with the inert-arc process, General Electric engineers recently found that dips in sodium hydroxide and sulfuric acid produce mirror-bright, fine-contoured welds as welded.

The first method tried at G. E. was wire-brushing, but this only folded the oxide and dirt into the surface of the aluminum. Next, sandpaper was tried. This was successful if all kerosene or lard oil which had been used as a lubricant in machining the aluminum had been completely removed before the sandpaper was applied. It was satisfactory for bulky work, but too slow and crude for cleaning small parts rapidly.

The logical answer seemed to be a chemical dip followed by washing, and nitric acid, which has been used extensively for aluminum brightening, was

tried. However, when a sample was welded after being cleaned by this method the weld bead was sprinkled with a black substance which accumulated in small surface pits. The discoloration was easily brushed off, but the pits remained to mar the surface of the bead.

When it was determined that the specks were not caused by too great a percentage of nitrogen in the argon welding gas or from faulty power supply, it was deduced that the cleaning method was responsible. Since the specks were rich in nitrides, the nitric acid was blamed, and sulfuric acid was tried in its place.

After a brief degreasing in a five per cent. solution of sodium hydroxide to remove all grease, oil, or wax, and a brief wash in water to remove most of the caustic and scum, the aluminum was dipped in a fifty per cent. sulfuric acid bath. This completed removal of the oxide skin and restored most of the surface brightness, and a hot water bath removed the acid and left the aluminum clean and dry. Welding tests made on samples cleaned by this method resulted in mirror-bright, fine-contoured beads as welded.

R. H. O.

Ground-Fault Neutralizer for Fort Peck, Montana, Has Novel Design Features to Combat Sixty Degrees Below Zero F.—Extremely low ambient temperatures at the installation site required that unusual design features be incorporated into the new 115,000-volt ground-fault neutralizer constructed by the General Electric Company for the War Department at Fort Peck, Montana. To combat the danger of cooling oil in the neutralizer from congealing at below-zero temperatures, G. E. engineers installed two thermostatically controlled 2.5-kw. Calrod * heating units in the bottom of the tank, the first time equipment of this type has ever utilized special heating devices. The Calrod units, supplied by a 230-volt, 60-cycle power supply, are automatically turned on when the oil temperature reaches −31 degrees Fahrenheit. The unit is designed to operate at temperatures as low as −60 degrees Fahrenheit.

This neutralizer, one of the largest units ever constructed by General Electric, is rated at 60 cycles, 115,000 volts, 180 to 90 amperes extended time. The "extended time" feature means that the unit is rated for continuous operation not to exceed 90 days per year. G. E. engineers further explained that this was the largest continuous-rating neutralizer ever constructed by G. E., although larger units with shorter rating time have been built. The neutralizer was given tests in the Company's High-Voltage Engineering Laboratory at Pittsfield, Mass. These tests consisted of short duration, high-voltage impulses applied to the coil winding.

Another novel feature incorporated by G. E. engineers prevents the Calrod units from heating the cold oil in the neutralizer's radiator tubes. The tank is designed so that when the oil temperature reaches −31 degrees Fahrenheit, the oil has contracted in volume and its level is below the top of the radiator tubes, thus preventing circulation. Only oil in the tank is heated and a saving in power is realized.

* Reg. U. S. Pat. Off.

Fort Peck is located on the Missouri River in northeastern Montana at the site of a dam across the Missouri River that was built by U. S. Army Engineers to assist in flood control and to improve navigation on the lower part of the river. Sometime after the dam was constructed a power plant with a 38,889-kva generator was added by the Army Engineers and was tied in with the Montana Power Company by a 161-kv. transmission line extending west from Fort Peck to Rainbow Dam, near Great Falls, Montana. Recently a 115-kv. transmission line has been built by the U. S. Bureau of Reclamation extending in a southeasterly direction from Fort Peck to Glendive, Montana, where the power is stepped down to 57-kv. and tied in with the Montana-Dakota Utilities Company. The length of this line is approximately 140 miles. Later it is contemplated extending the line another 80 miles in a southwesterly direction from Glendive to Miles City.

The transmission line is of the wood H-frame construction and is built without overhead ground wires. In order to extinguish the arcs due to single-phase-to-ground faults which may occur on the line following lightning flash-over, the ground-fault neutralizer is installed between neutral and ground of the step-up transformer bank at Fort Peck on the 115-kv. system. It is expected that this unit will take care of a total of approximately 260 miles.

The neutralizer is essentially a reactance coil with numerous taps which can be selected by a motor-operated tap changer. The reactor is tuned with the capacitance of the system so that when a line-to-ground fault occurs, the reactor will furnish a lagging current equal in value and opposite in phase from the charging current at the fault, so that the net current at the fault will be practically zero (except for line losses) and the arc will be extinguished for lack of current to feed it. Experience has proven that these neutralizers on various systems have taken care of from 65 to 95 per cent. of all faults without oil-circuit breaker operation, thus greatly improving the continuity of operation and reducing wear on the oil-circuit breakers.

R. H. O.

Weather Forecasting. Herbert B. Brooks. (*Electronics*, Vol. 19, No. 10). For several decades the winds aloft have been measured by observing with a theodolite the motion of free balloons inflated with hydrogen or helium. The present network of a few hundred pilot balloons distributed over North America is almost dense enough for complete knowledge of the wind in clear weather, up to the stratosphere. But bad weather is more important than good weather, and a pilot balloon run ends when the balloon enters a cloud. Using radio direction-finding and position finding techniques developed for combat, the weather services now measure winds to higher altitude and with greater accuracy in nearly any kind of weather.

The latest type radio direction finding receiver went into production in 1944 and soon became standard for use in the Air Weather Service. The ground equipment measures azimuth and elevation angle and the transmitter signals its height by means of a baroswitch. The transmitter is now combined with radiosonde elements, which signal the air temperature and humidity on the flight.

The use of radar in storm detection is new and the job is still being studied. Microwave radar indicates the location of rain or other precipitation with

great accuracy and resolution. Thunderstorm behavior can be forecast for 15 minutes to several hours using trends indicated by past observations. Radar has proven especially useful in detecting thunderstorm areas so that airmen can avoid them. Many other groups will soon benefit by accurate short range shower, lightning, hail, windstorm, and hurricane warnings from radar observations. The army is conducting basic researches intended to answer the following questions:—

(1) What is the effect of various radar parameters on echo strength?

(2) How can storm echo be interpreted in weather terms?

(3) What is the effect of weather in scattering and absorbing the radar energy?

(4) What is the distribution of drop and ice crystal size and number in various cloud types?

Storm detection on the ground and in the air is expected to play a part in the Army Air Forces all weather flying project. Thunderstorms cause hazard and discomfort in flying due to their turbulence, icing, radio interference, and occasional damage to aircraft from direct hits by lightning.

The Weather Bureau, Army, Navy, and National Advisory Committee for Aeronautics are conducting a research project on thunderstorm microstructure near Orlando, Florida. Radar is used for detection, mapping, and surveillance of thunderstorm rain cores, and for taking some of the observations.

R. H. O.